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# Late Quaternary palaeoclimates and human-environment dynamics of the Maloti-Drakensberg region, southern Africa

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A B S T R A C T

The Maloti-Drakensberg Mountains are southern Africa's highest and lie at a crucial interface between the sub-continent's drier, colder, more seasonal interior and its perennially productive sub-tropical coastal belt. Their location, high elevation, and topography make them ideal for exploring human responses to late Quaternary climatic change. This paper reviews and synthesizes palaeoclimatic and palaeoenvironmental data from the Maloti-Drakensberg region over the past 50,000 years. It then employs 325 calibrated radiocarbon dates to examine human occupational trends across the region and its component parts, discuss human-environment dynamics over this time-span, and explore patterning between particular phases of climatic change and the timing, mode, and motives of its exploitation by people. Key findings are that the region's Lesotho core may have served as a refugium for human populations during drier, more unstable climatic periods and that intensified exploitation of freshwater fish likely helped address resource stress in cooler ones. An agenda for future palaeoenvironmental and archaeological research is also mapped out.



## 1. Introduction

The Maloti-Drakensberg Mountains are among Africa's highest and topographically most diverse regions and an important centre of plant and animal endemism (Kingdon, 1989; World Wildlife Fund, 2017). They also preserve a rich archaeological record that includes one of Africa's best-understood concentrations of rock art (Lewis-Williams, 2003). This combination was instrumental in part of the region being designated a World Heritage Site (UNESCO, 2018).

From a palaeoclimatic and palaeoanthropological perspective, the Maloti-Drakensberg's significance is twofold. First, they lie at a crucial interface between southern Africa's perennially productive sub-tropical coastal forelands and its more seasonal, colder, drier interior. Second, their elevation and topographic diversity are likely to have reinforced their susceptibility to late Quaternary climatic shifts (Kohler and Maselli, 2009). They therefore offer an excellent opportunity for exploring human responses to changing environmental conditions along such dimensions as technology, subsistence, demography, settlement and mobility decisions, and the structures used to maintain social connectivity over distance. Current archaeological data allow us to investigate these questions across the last 80,000 years (Stewart et al., 2012, 2016).

A wide range of palaeoenvironmental proxies exists with which to do this, many recovered from archaeological excavations, others from contexts such as peat bogs where human input can be excluded. These archives have not previously been coherently summarized on a regional scale with a view to assessing their potential for understanding late Quaternary climatic change or the latter's implications for human behaviour.

We do this here by first discussing the Maloti-Drakensberg's current climate and ecology and the main controls on these. Next, we critically consider the sources available for understanding their

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climatic history, emphasizing the importance and challenges of integrating information from as many proxies as possible. The main part of our paper then reviews current knowledge of Maloti-Drakensberg palaeoclimates and palaeoenvironments over the last ~50 kyr. Following strategies trialled elsewhere (e.g. Crema et al., 2016; Manning and Timpson, 2014; Méndez et al., 2015; Williams et al., 2015), we draw upon a database of archaeological radiocarbon dates that we are developing to examine human occupational trends across and within the region. Finally, we discuss human-environment dynamics over this time-span, searching for patterning between particular phases of climatic change (relative stability and instability, cooling and warming, greater or lesser precipitation), and the timing, mode, and motives of the region's exploitation by people. In our conclusion we identify key topics for future palaeoenvironmental and archaeological research in this highest region of southern Africa.

## 2. Defining the Maloti-Drakensberg: climate and ecology

The Maloti-Drakensberg Mountains lie at the heart of the region that takes their name (Fig. 1). Collectively, they form a deeply dissected plateau, anchored in the east by the uKhahlamba-Drakensberg Escarpment, the watershed between the Indian and Atlantic Oceans. This is one of three sub-parallel ranges that collectively fill out a roughly quadrangular 55,000-km$^2$ massif and consist of Drakensberg Group flood basalts capping Karoo Supergroup sedimentary strata. Intense fluvial erosion of these strata has produced an intricate network of drainages feeding into southernmost Africa's largest river, the Orange, known in Lesotho as the Senqu.

The Senqu and its immediate tributaries flow west of the Escarpment. Numerous other rivers drain east into the Indian Ocean. West of the Senqu, the Central and the Front Ranges of the Maloti intervene before one reaches Lesotho's lowlands. Two important tributaries of the Senqu, the Senqunyane and the Makhaleng, run southward between them. The Caledon River, which forms Lesotho's western border, draws almost all its water from precipitation falling on the Front Range, only joining the Orange after both rivers enter the highveld grasslands that occupy most of South Africa's Free State province. Finally, to Lesotho's south the Drakensberg Mountains extend into South Africa's Eastern Cape Province. To facilitate our discussion we divide the Maloti-Drakensberg into six sub-regions: (1) the northern KwaZulu-Natal Drakensberg; (2) the southern KwaZulu-Natal Drakensberg; (3) the Eastern Cape Drakensberg; (4) highland Lesotho; (5) lowland Lesotho; and (6) the eastern Free State (Figs. 2 and 3).

The Maloti-Drakensberg's climate is continental, with cold, dry winters and warm, humid summers. Lying in southern Africa's summer rainfall zone (SRZ), over 75% of its rainfall falls between October and March, mostly as a result of easterly airflow from the Indian Ocean (Schulze, 2008). Precipitation totals vary tremendously with altitude and locality, decreasing from east to west because of the pronounced rain-shadow cast by the uKhahlamba-Drakensberg Escarpment. Thus, while mean annual precipitation for the latter typically exceeds 1500 mm (Schulze, 2008), values of 580–700 mm are recorded in the upper Senqu and Caledon Valleys (Bawden and Carroll, 1968). Temperatures vary drastically by altitude, as well as seasonally and diurnally, with mean annual values of ~15 °C in the Caledon Valley (~1600 m a.s.l.) but $\leq$6 °C on the highest mountains ($\geq$3000 m a.s.l.) (Grab, 1997). Corresponding mean mid-summer maxima are respectively 29 °C and 17 °C, with mean mid-winter minima of 4.3 °C and −6.1 °C (Grab and Nash, 2010). Snow can fall at any time, but especially between May and September, persisting on south-facing slopes for up to six months, while frost is also widespread (Bawden and Carroll, 1968).

Ecologically, the Maloti-Drakensberg lies within southern Africa's Grassland Biome (Mucinda and Rutherford, 2006). As this implies, grasses dominate its vegetation, with trees rare except in protected locations such as valleys. Plant communities are significantly differentiated by altitude, with aspect locally significant and differences in rainfall producing further contrasts between areas below the Escarpment to the east and those west of the Front Range. The highest elevations (~2900–3482 m a.s.l) support an Afroalpine short shrubland that includes ericaceous taxa, Asteraceae, and shorter, less palatable, $C_3$-photosynthesizing *Festuca*- and *Merxmuellera*-dominated grasses (Killick, 1978; Mucinda and Rutherford, 2006). Numerous alpine bogs help regulate rainwater flow into the Orange-Senqu river system (van Zinderen Bakker and Werger, 1974).

Lying between ~1900 and 2900 m a.s.l. the rest of highland Lesotho, plus adjacent areas of the Eastern Cape Drakensberg, is covered by $C_4$-dominated *Themeda-Festuca* grassland with patchy shrublands where *Passerina montana* is common (Mucinda and Rutherford, 2006). Due to its large altitudinal range it contains several altitude-specific vegetation belts with *Themeda triandra*, a $C_4$ grass that provides excellent pasture (Jacot Guillarmod, 1971), dominating at lower elevations (up to ~1900–2100 m a.s.l. on northern (cooler) slopes, but reaching ~2700 m a.s.l. on southern (warmer) ones). Note that the susceptibility of much of the Maloti-Drakensberg to tracking this altitudinal variation between predominantly $C_4$ and higher $C_3$ grasslands in response to shifting temperatures (Fig. 4) provides the basis for using $\delta^{13}C$ analysis of ungulate remains, rockshelter sediments (partly built up via introduction of grass bedding), and offsite sedimentary sequences to track late Quaternary climate changes (Parker et al., 2011; Roberts et al., 2013). The same approaches have also been followed in the Caledon Valley (Smith, 1997; Smith et al., 2002), which is characterized by a *Cymbopogon-Themeda-Eragrostis* $C_4$ grassland with numerous trees and evergreen shrubs that also intrudes along the lower reaches of the Senqu and its principal tributaries.

East of the Escarpment, Acocks' (1975) highland sourveld extends between 2150 and 1350 m a.s.l. *Themeda triandra* occurs frequently here too, but forbs are particularly noteworthy. *Protea* spp. (otherwise strongly associated with the Fynbos Biome of southwestern South Africa) may be common on mountain slopes, while montane forest dominated by *Podocarpus latifolius* characterizes protected gorges and south-facing slopes. Areas of southern tall grassveld — an open savanna of *Acacia sieberanna* in a mixed grassland dominated by *T. triandra* and *Hyparrhenia* spp. — occur along valleys and at lower elevations below this, particularly in areas draining northeast toward the Thukela River.

Unsurprisingly, grazers were common in precolonial times, especially black wildebeest (*Connochaetes gnou*), red hartebeest (*Alcelaphus buselaphus*), plains zebra (*Equus quagga*), blesbok (*Damaliscus pygargus phillipsi*), mountain reedbuck (*Redunca fulvorufula*), springbok (*Antidorcas marsupialis*), and the now extinct blue antelope (*Hippotragus leucophaeus*). Eland (*Taurotragus oryx*), a mixed feeder, was also common, with two small-medium species — oribi (*Ourebia ourebi*) and klipspringer (*Oreotragus oreotragus*) — some of the few antelope present in the Afroalpine belt (Plug, 1997; Plug and Mitchell, 2008). As well as geophytes like *Watsonia* spp. and *Moraea* spp., people also consumed a wide variety of fruits, seeds, and grasses (Carter, 1978). Along the Senqu (and probably other major rivers too) fish formed another important resource (Mitchell et al., 2011).

## 3. Sources of palaeoclimatic and palaeoenvironmental evidence

Initial studies of Maloti-Drakensberg palaeoenvironments focused overwhelmingly on how far its highest mountains

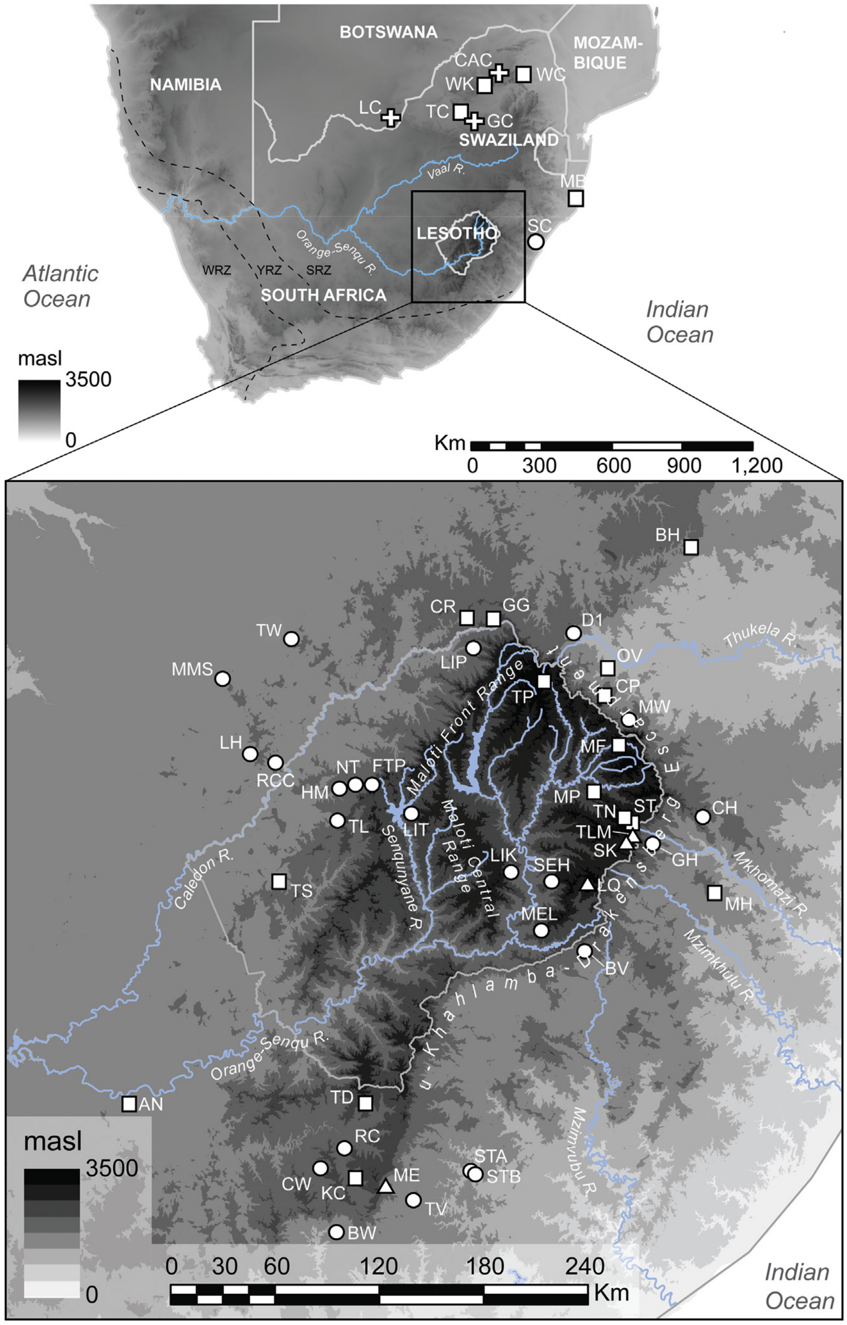


**Fig. 1.** Map of the Maloti-Drakensberg region (below) and its location within southern Africa (above) showing localities/sites mentioned in the text. Circles: archaeological sites; squares: non-archaeological sedimentary sequences; crosses: speleothem records; triangles: glacial/periglacial landforms. AN: Aliwal North; BH: Braamhoek; BV: Belleview; BW: Bonawe; CAC: Cold Air Cave; CW: Collingham; CP: Cathedral Peak; CR: Craigrossie; CW: Colwinton; D1: Diamond 1; FTP: Fateng Tsa Pholo; GC: Gladysvale Cave; GG: Golden Gate Highlands National Park locales; GH: Good Hope; HM: Ha Makotoko; KC: Kilchurn; LC: Lobatse Cave; LH: Liliehoek: LIK: Likoaeng; LIP: Liphofung; LIT: Lithakong; LQ: Leqooa; MB: Mfabeni: MF: Mafadi; ME: Mount Enterprise; MEL: Melikane; MH: Mahwaqa; MMS: Mauermanshoek; MP: Mokhotlong Peats; MW: Mhlwazini; NT: Ntloana Tšoana; OV: Okhombe Valley (Masotcheni Formation); RC: Ravenscraig; RCC: Rose Cottage Cave; SB: Sibudu Cave; SEH: Sehonghong; SK: Sekhokong; ST: Sani Top; STA: Strathalan A; STB: Strathalan B; TC: Tswaing Crater; TD: Tiffindell; TL: Tloutle; TLM: Tsatsa-La-Mangaung; TN: Thabana Ntlenyana 'Site 1'; TP: Tlaeeng Pass; TS: Tsoaing; TV: Te Vrede; TW: Twyfelpoort; WC: Wolkberg Cave; WK: Wonderkrater.

sustained glaciers during the Last Glacial Maximum (LGM) (Boelhouwers and Meiklejohn, 2002). However, the last two decades, in particular, have also seen several other archives explored. Derived from both archaeology- and non-archaeology-bearing sedimentary sequences, they reflect the work of multiple researchers over many years, often operating in logistically challenging conditions (e.g. Fitchett et al., 2016a, 2016b, 2017a; Grab and Mills, 2011; Grab et al., 2005; Parker et al., 2011; Plug and Mitchell, 2008; Roberts et al., 2013; Smith et al., 2002; Stewart et al., 2012, 2016). Individually and collectively these archives nevertheless still contain many spatiotemporal gaps. Other lacunae reflect the innovation of new analytical techniques since some sites were first investigated or a dearth of qualified (and interested) analysts able to study samples already recovered.

More fundamentally, when attempting to synthesize existing palaeoclimatic/palaeoenvironmental data and relate them to the

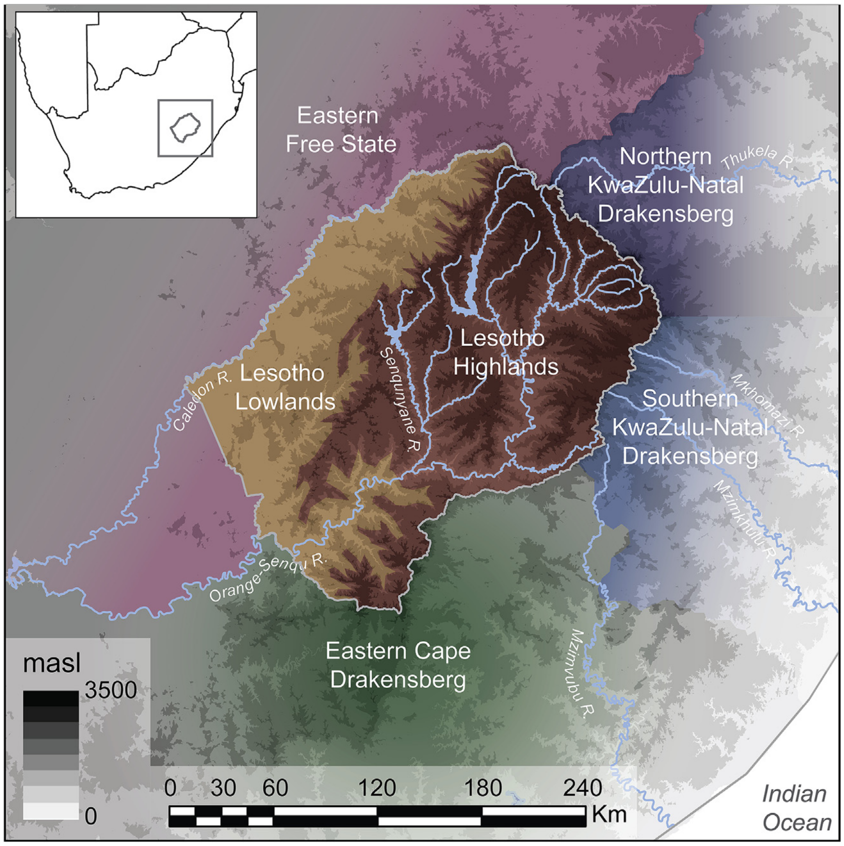


**Fig. 2.** Map of the six major Maloti-Drakensberg sub-regions discussed in the text.

dynamics of past human populations several points must be remembered. First, much proxy evidence from archaeological sites relates to what people introduced to them: charcoal is principally a by-product of firewood, phytoliths of food waste, artefacts, and bedding materials, and large mammal bones/teeth of animals hunted for their meat and hides. In all these cases people exercised choice in what they harvested and brought back with them (Shackleton and Prins, 1992), decisions with potentially significant implications on the environmental representativeness of resulting proxy data. Secondly, such archives can only have formed when people were present, although when they were absent others (e.g. sedimentary records) may have continued to accrue, sometimes even more readily (e.g. microfaunal assemblages, given that the owls that typically concentrate them do not usually co-reside with people; Avery, 1982). Palaeoenvironmental archives that exclude human action as a source of proxy accumulation or that form more continuously, such as wetland cores, offer vital complements to archaeological data points.

Because of this, and because different proxy data respond to climatic change at varying rates, it is essential to use as wide a variety of signals as possible, acknowledging that they may display different degrees of temporal lag or reflect change at more local rather than more regional scales (Meadows, 2014). Even so, the shifts registered may be subject to equifinality, complicating attempts at directly inferring changes in temperature or moisture: faunal oxygen isotope ratios, for example, reflect both dietary and climatic factors (Smith et al., 2002:691).

Finally, many sequences remain hampered by chronologies (mostly of radiocarbon origin) that are only coarsely resolved or varyingly reported using both calibrated and uncalibrated dates. We have therefore (re-)calibrated the radiocarbon dates employed here using OxCal 4.2.4 (Bronk Ramsey, 2009) and the southern hemisphere calibration curve (Hogg et al., 2013), although in some cases (the Mahwaqa wetland record from KwaZulu-Natal and western Lesotho's Tsoaing sediment sequence) the dates we cite depend on interpolation from published age-depth models (Grab et al., 2005; Neumann et al., 2014). We also present a region-wide summed probability distribution (SPD) using the OxCal (4.2.4.) Sum command, which combines probability distributions by adding and in effect averaging equally weighted individual distributions (Bronk Ramsey, 2009). Despite critiques of SPDs for discerning detailed demographic patterns (e.g. Contreras and Meadows, 2014), we feel that it is nevertheless an appropriate tool for exploring long-term, region-wide occupational trends on a preliminary basis. Because it matches the upper limit of the radiocarbon technique, we restrict our review to the past ~50 kyr, but emphasize that human history in the Maloti-Drakensberg has at least double — if not more than quadruple — this antiquity (Carter, 1978).

## 4. Maloti-Drakensberg palaeoclimates and palaeoenvironments: a 50-kyr synthesis

### 4.1. Marine Isotope Stage 3 50–24 ka

Fig. 5 presents proxy data from palaeoenvironmental archives in the Maloti-Drakensberg region that extend back beyond 18 ka, along with a selection of major palaeoclimatic records from the broader SRZ. Details on the location, setting, and chronology of all the sites we discuss are given in Supplementary Tables 1 and 2.

Our earliest detailed evidence comes from Melikane, a highland Lesotho rockshelter with a pulsed archaeological sequence


**Fig. 3.** Landscape views of the Maloti-Drakensberg's major sub-regions. Lowland Lesotho: courtesy and copyright Charles Arthur; eastern Free State: courtesy and copyright Creative Commons user JMK under license type CC BY-SA 3.0; other photos taken by BAS.

stretching back to ~83–80 ka (Stewart et al., 2012). Analyses of phytoliths and sedimentary $\delta^{13}C$ (mean = −23.1‰, n = 21) suggest that all the sediments deposited here from 83 to 24 ka were introduced when $C_3$-dominated Afroalpine grassland surrounded the site (Stewart et al., 2016) (Fig. 5a, j–k). Assuming a temperature drop of −0.6 °C per 100 m increase of altitude (Smith et al., 2002), this depression of Afroalpine vegetation belts now found ≥2700 m a.s.l. suggests that average temperatures were ≥5 °C cooler than present, consistent with a pioneering study of $\delta^{13}C$ values in zebra teeth recovered from Carter's (1978) earlier excavations at the same site that implied a 75–84% $C_3$-rich diet for these grazers (Vogel, 1983).

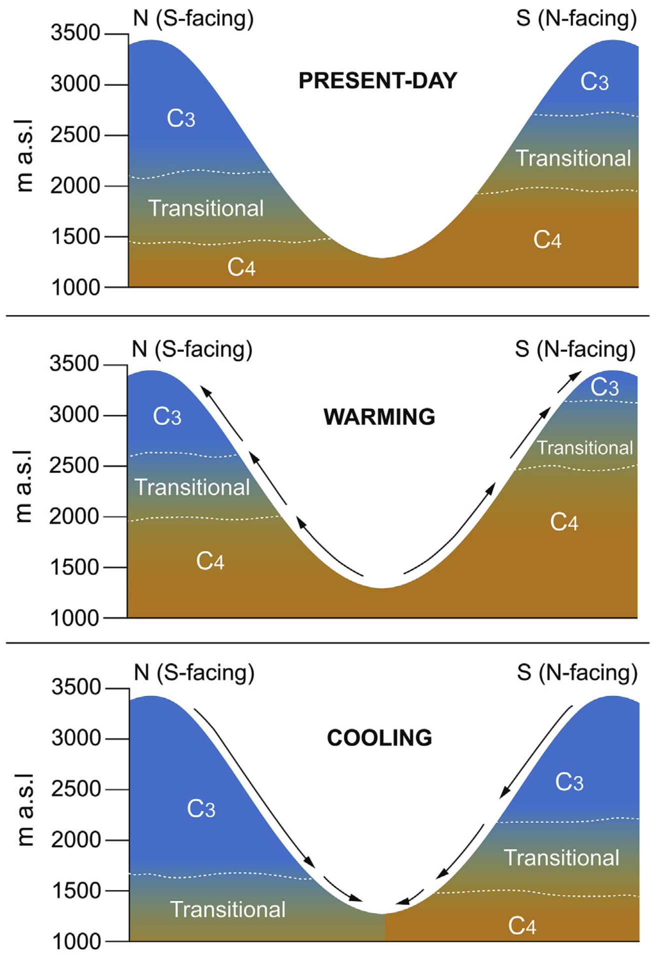


**Fig. 4.** Schematic illustrations of temperature-mediated shifts in $C_4$ and $C_3$ vegetation belts in the Maloti-Drakensberg region on north *versus* south slopes (modified after Roberts et al., 2013).

Long considered a period of enduring aridity in southern Africa's interior, Marine Isotope Stage (MIS) 3 is increasingly recognized as a climatically volatile period that included phases of high precipitation and moisture availability (Mitchell, 2008). Melikane registers two occupation pulses, the earlier of which ~50 ka coincides with the start of our review. These levels (Layers 22–16) contain its most abundant bulliform phytoliths, which preferentially silicify with elevated moisture, and its highest ratio of woody (ligneous dicotyledon) to grassy (Poaceae) morphotypes (Fig. 5j–k). Both observations suggest a highland landscape with high moisture availability and more woodland than in any other pre-Holocene occupation pulse. Four $\delta^{13}C$ sediment samples provide a broadly $C_3$ (cool) signature (mean = −23.2‰), though a high sedimentary input from woody vegetation introduced as firewood and from plant foods, especially geophytes (Sealy, 1986:43–45), likely exaggerates this value (Stewart et al., 2016). As yet unpublished data from the Likoaeng open-air site some 40 km to the north along the Senqu Valley suggest that human activity may have had a depletion effect of roughly 4.4‰ relative to the environmental background signal (Julia Lee-Thorp, personal communication, 2010).

Broadly contemporaneous records in the wider SRZ agree well with these data (Fig. 5f–i, m–p). In multiple caves (Gladysvale, Lobatse, and Wolkberg) across South Africa's Savanna Biome conditions were humid enough to allow carbonate deposition for speleothem growth ~56–42 ka (e.g. Holzkamper et al., 2009), while at the Tswaing impact crater detrital input from enhanced precipitation was high ~55–48 ka (Kristen et al., 2007) (Fig. 5n). Closer to the Maloti-Drakensberg, higher temperatures, increased summer rainfall, and greater vegetation density are inferred ~48 ka compared to older levels at Sibudu Cave in KwaZulu-Natal's coastal belt (Bruch et al., 2012; Glenny, 2006).

Substantial changes are apparent in Melikane's second MIS 3 occupation pulse ~46–38 ka (Layers 15–6). Drops in bulliform phytolith frequencies and, especially after 42 ka, in the ratio of dicotyledon to Poaceae morphotypes suggest major reductions in woodland under markedly drier conditions. $C_3$ grasses still heavily dominated the landscape (90–95%) as this pulse started, but after ~42 ka slightly higher $\delta^{13}C$ sediment values (−23.9‰ to −22.8‰) and minor increases in $C_4$ grass phytoliths probably reflect a shift towards drier conditions and/or reduced atmospheric $CO_2$ ($pCO_2$) (Stewart et al., 2016) (Fig. 5a, j). A third possibility — higher temperatures — is less likely given that high altitude fynbos elements (*Rhamnus* sp., *Protea* sp., *Leucosidea sericea*, plus *Erica* sp. after ~41.5 ka) dominate the relevant charcoal assemblages (Stewart et al., 2016). Melikane also shows major changes in site formation processes beginning ~42 ka, with episodes of intense roof collapse alternating with recurrent influxes of colluvial gravels signalling heightened climatic instability (Carter, 1976; Stewart et al., 2012). However, the persistence of charcoals from riparian taxa throughout this phase suggests that the Senqu river system always sustained ample water flow (Stewart et al., 2016).

Melikane's record accords well with other regional proxy data. Near Thabana Ntlenyana, Lesotho's highest mountain, the 'Site 1' colluvial/palaeosol sequence indicates relatively wet, warm conditions before the start of an extended period of colluviation ~44–42 ka (Fig. 5l) that likely reflects a colder, drier climatic regime (Grab and Mills, 2011). Similar changes are registered across the Escarpment in KwaZulu-Natal's Midlands where the Masotcheni Formation consists of massive colluvial mantles deposited during phases of heightened aridity, punctuated by numerous palaeosols reflecting brief shifts to more humid conditions. Various Masotcheni locales are well dated using OSL, IRSL, and radiocarbon to ~46–37 ka (e.g. Botha and Partridge, 2000; Clarke et al., 2003), including one in the northern KwaZulu-Natal Drakensberg (Temme et al., 2008). Nearby in the eastern Free State's Golden Gate Highlands National Park, enhanced aeolian activity under erosive periglacial conditions favoured the sporadic formation of sand ramps, the earliest of which is dated by OSL to ~45 ka (Telfer et al., 2012, 2014).

An occupational and sedimentary hiatus at Melikane ~38–24 ka precluded accrual of proxy data there later in MIS 3, but this interval is largely captured at Sehonghong, 40 km further north (Loftus et al., 2015; Pargeter et al., 2017). Freshly obtained palaeoenvironmental data include $\delta^{13}C$ sediment values from the entirety of this rockshelter sequence and $\delta^{13}C$ and $\delta^{18}O$ measurements of large ungulate tooth enamel from strata dated to ~35–29 ka (Stewart et al., 2012, 2016). Consistent with Melikane, Sehonghong's $\delta^{13}C$ sediment values suggest a pre-Holocene landscape heavily dominated by $C_3$ vegetation (mean = −23.7‰, n = 20), with last glacial temperature depressions of $\geq 5$ °C relative to today (Loftus et al., 2015) (Fig. 5b). The lowest value (−24.7‰) at ~30 ka matches the mean of three others from a broadly coeval stratum at Ntloana Tšoana rockshelter in western Lesotho, where five MIS 3 values at the adjacent site of Ha Makotoko range between −23.3‰ and −24.5‰ (Roberts et al., 2013) (Fig. 5c–d). Cold, periglacial conditions around this time (~29–28 ka) are also evidenced by renewed aeolian and colluvial activity in the Golden Gate Highlands National Park (Telfer et al., 2012) and the Okhombe Valley (Temme et al., 2008) respectively. The $\delta^{13}C$ values of herbivore tooth enamel at Sehonghong dated to ~35–29 ka fall between −11.1‰ and −5.8‰ (mean = −8.1 ± 1.4‰, n = 29). As pure

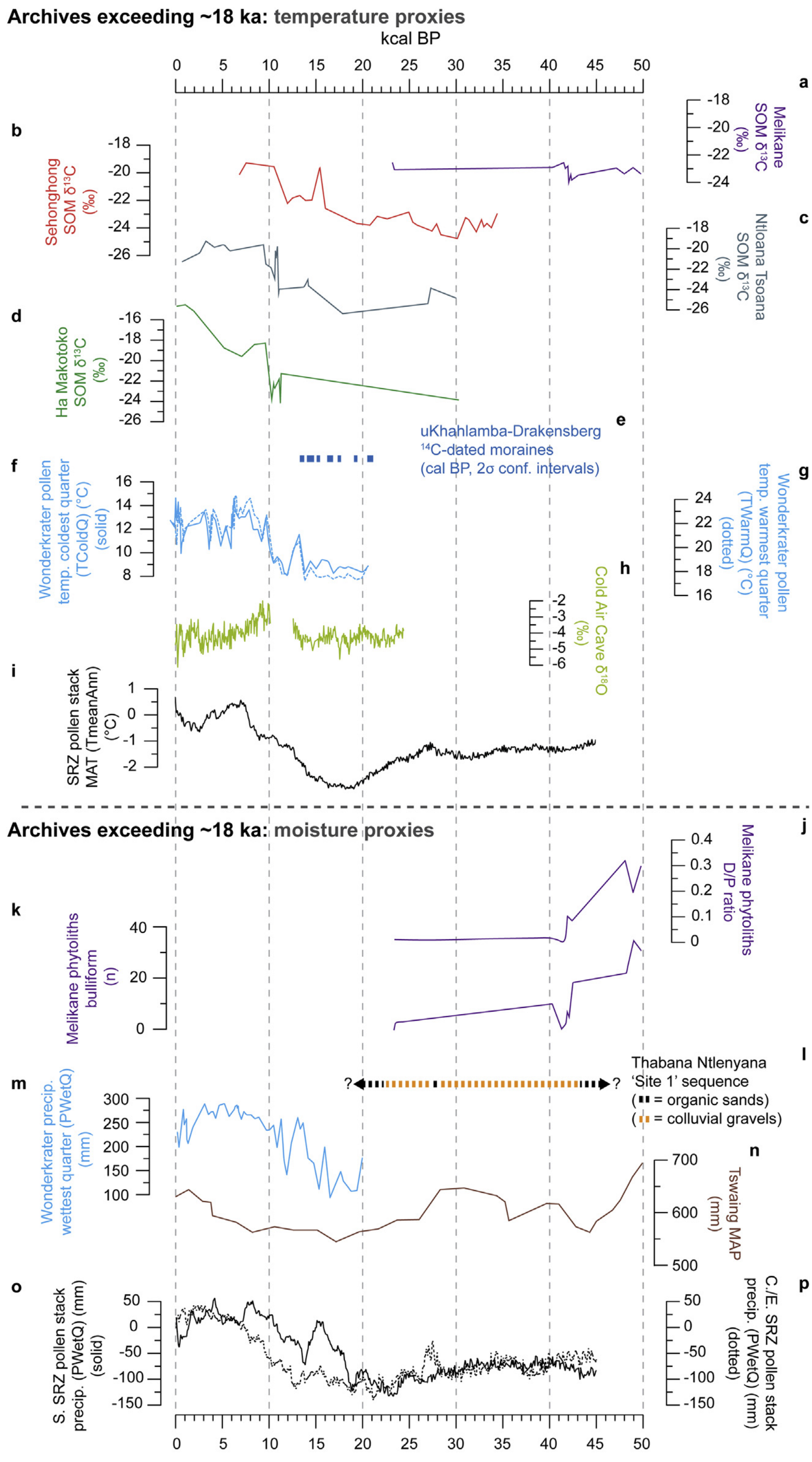


**Fig. 5.** Maloti-Drakensberg palaeoclimatic/environmental proxy data for selected archives and others from the broader summer rainfall zone (SRZ) exceeding ~18 ka. a: Melikane sediment $\delta^{13}C$ (Stewart et al., 2016); b: Sehonghong sediment $\delta^{13}C$ (Loftus et al., 2015); c: Ntloana Tšoana sediment $\delta^{13}C$ (Roberts et al., 2013); d: Ha Makotoko sediment $\delta^{13}C$ (Roberts et al., 2013); e: ages of various $^{14}C$-dated moraines on the uKhahlamba-Drakensberg Escarpment (Mills et al., 2009b); f: Wonderkrater pollen reconstructed mean temperature during the coldest quarter (of the year) (TColdQ) (Truc et al., 2013); g: Wonderkrater pollen reconstructed mean temperature during the warmest quarter (TWarmQ) (Truc et al., 2013); h: Cold Air Cave speleothems $\delta^{18}O$ (Holmgren et al., 2003); i: SRZ pollen stack reconstructed mean annual temperature (TmeanAnn) (relative to present-day) (Chevalier and Chase, 2015); j: Melikane ratio of dicotyledon to Poaceae (D/P) phytoliths (Stewart et al., 2016); k: Melikane counts of bulliform phytoliths (Stewart et al., 2016); l: Thabana Ntlenyana 'Site 1' $^{14}C$-dated colluvial/palaeosol sequence (Grab and Mills, 2011); m: Wonderkrater pollen reconstructed mean precipitation during the wettest quarter (PWetQ) (Truc et al., 2013); n: Tswaing Impact Crater total inorganic content (TIC) (Kristen et al., 2007); o: central/eastern SRZ pollen stack reconstructed mean precipitation during the wettest quarter (relative to present-day) (Chevalier and Chase, 2015); p: northern SRZ pollen stack reconstructed mean precipitation during the wettest quarter (relative to present-day) (Chevalier and Chase, 2015).

$C_3$- and $C_4$-feeders have enamel value ranges of −14‰ to −12‰ and 0‰ to +2‰ respectively (Vogel, 1978), these animals' diets must have been predominantly $C_3$ in composition. Unlike the sediment samples, however, they also included substantial contributions of $C_4$ plants (up to 40%), suggesting that the zebras and alcelaphines in question migrated seasonally to lower altitudes beyond highland Lesotho. A strong deviation from this pattern (mean = −10.8‰, n = 3) implies an almost exclusively $C_3$ diet ~33 ka and perhaps a sharp drop in temperatures (Loftus et al., 2015).

### 4.2. The Last Glacial Maximum 24–17 ka

Both Melikane and Sehonghong register occupation with associated environmental data in the early stages of the LGM ~25–24 ka. Like mid-MIS 3, sediment $\delta^{13}C$ and phytolith records at Melikane suggest grassland cover with a strong $C_3$ signature most likely derived from sour Afroalpine grasses, plus a $C_4$ component (Stewart et al., 2016) (Fig. 5a). Once again, however, the $C_4$ signal probably reflects drying and/or lower $pCO_2$ levels during the onset of the LGM rather than warmer temperatures since these levels also possess the lowest dicotyledon/Poaceae phytolith ratio of the entire sequence (Fig. 5j). Those trees and shrubs still present were likely restricted to deeper river corridors with sufficient shelter and surface water to support them, but the presence at Sehonghong of common duiker (*Sylvicapra grimmia*) and steenbok (*Raphicerus campestris*), species that browse and require cover (Plug and Mitchell, 2008), confirms that riverine shrubs and bushes were still available in some density. Drying and coldness are further suggested by the charcoals from the ~24 ka levels at Melikane. Several mesic streamside taxa present throughout MIS 4 and 3 now disappear, leaving a much more limited range of frost-resistant species (*Erica drakensbergensis*, *Protea* sp., *Leucosidea sericea*, and *Olea europaea*). Further west, at Rose Cottage Cave in the Caledon Valley early MIS 2 is also marked by the presence of *Protea* sp., along with *L. sericea* and other heathland species (Wadley et al., 1992).

Comprising anthropogenic materials mixed with colluvial sediments and host bedrock attrition products from roof fall debris, the sediments from the ~24 ka levels at Melikane derived from landscape erosion as well as freeze-thaw processes. The colder and drier conditions thus implied (Stewart et al., 2012) may also be indicated high on the Escarpment, where a thick, organic-poor colluvial layer at Thabana Ntlenyana ‘Site 1’ is radiocarbon dated to between ~27.4 and ~23.1 kya (Grab and Mills, 2011) (Fig. 5l). Augmenting this picture is an OSL date of ~23 ka for another episode of aeolian deposition in the Golden Gate Highlands National Park (Telfer et al., 2012).

Throughout the Maloti-Drakensberg, conditions deteriorated sharply around ~24 ka, with increased cold widely recognized across southern Africa at this time (Scott et al., 2012). Geomorphological indications of periglacial conditions along the Escarpment are extensive (Grab and Knight, 2016), accompanied by good evidence of localized niche (cirque) glaciers. This includes debris ridges interpreted as glacial moraines ~3000 m a.s.l. on steep south-facing slopes of the Sekhokong and Tsatsa-La-Mangaung Ranges in easternmost Lesotho (Fig. 5e); dates of ~20.8 ka and ~19.6 ka run on soil organic matter overlap with the height of the LGM, but may be only minimal ages (Mills et al., 2009a, 2009b). The snow accumulation necessary to sustain these glaciers implies that the LGM brought higher precipitation to the Maloti-Drakensberg, and perhaps the wider SRZ as well (Mills et al., 2012). Snow cover patterns suggest that today most (63%) snowfall events occur in a tightly restricted winter window (June–August), with 80% of them caused by westerly cold fronts and associated cut-off lows (Mulder and Grab, 2009). Together, these data may indicate that during the LGM more of the region's annual precipitation fell in winter than is currently the case (Mills et al., 2012).

Similar periglacial landforms, including blockstreams, protalus ramparts, and solifluction deposits, are recorded further south in the Eastern Cape Drakensberg down to ~1700 m a.s.l., though the presence of rock glaciers (Lewis and Hanvey, 1993) cannot be substantiated (Mills et al., 2017). Arguments that temperatures fell by as much as 10 °C or more, and that snowlines dropped to ~2100 m a.s.l., (Lewis and Illgner, 2001), are likewise improbable, and at odds with mass balance modelling and niche glacier reconstructions for highland Lesotho (Mills et al., 2012). All these periglacial features could, in fact, have formed under mean temperature depressions of 6 °C, as implied by other SRZ proxy records (Holmgren et al., 2003; Truc et al., 2013). That post-24 ka pollen spectra at Strathalan B (1340 m a.s.l) resemble those of Afroalpine environments now found ≥1500 m higher underlines the effect that this depression had (Opperman and Heydenrych, 1990).

### 4.3. Marine Isotope Stage 2 after the LGM 17–13 ka

Fig. 6 presents Maloti-Drakensberg proxy archives post-dating the LGM, again accompanied by selected major archives from the broader SRZ. In southern Africa as elsewhere, the period immediately after the LGM was climatically complex, with dry conditions registered north of the Vaal River, but more fluctuating conditions further south (Scott et al., 2012). In the Maloti-Drakensberg peat formation at the Braamhoek wetland site ~16 ka implies relatively moist conditions, while pollen spectra there and at Mfabeni near the KwaZulu-Natal coast identify a major summer rainfall spike ~17–15 ka (Chevalier and Chase, 2015). In our region's southwest, the Aliwal North pollen sequence likewise indicates high moisture availability ~16 ka (Coetzee, 1967; Scott et al., 2012) (Fig. 6b). Pdf-based pollen analyses of sites across the SRZ (Chevalier and Chase, 2015; Truc et al., 2013) suggest that post-LGM southeastern Africa experienced sustained temperature depressions (hovering just above LGM minima) through most of Heinrich Stadial 1 (HS1) (Fig. 6l). Locally relevant sequences include Braamhoek and Mahwaqa, a high-elevation wetland in KwaZulu-Natal's Midlands. Basal pollen assemblages at both sites contain high frequencies of fynbos elements, including Ericaceae and Restionaceae, indicating cool and probably fairly humid conditions that may also imply greater winter rainfall (Finné et al., 2010; Neumann et al., 2014; Norström et al., 2014) (Fig. 6a, c, m, s). Sharply reduced temperatures and higher (winter?) rainfall are also attested by glacial moraines in Lesotho's Leqooa and Tsatsa-La-Mangaung Ranges (Fig. 5e), though associated radiocarbon ages (~17.2, ~16.5, and ~15.5 ka) should be treated as minima since they were run on (potentially recycled) soil organic matter (Mills et al., 2009b). The same period (~17–16 ka) saw the most rapid deposition of OSL-dated aeolian material in the Golden Gate Highlands National Park, suggesting enhanced cold, windiness and/or perhaps (local?) aridity.

Two archaeological sites complement these observations. Mean $\delta^{13}C$ and $\delta^{18}O$ values of −2.5‰ and 0.6‰ from grazer teeth at Rose Cottage Cave (lower part of Layer DB, n = 7) signal cool temperatures (grazer diets with ~70% $C_4$ plants) and high moisture availability ~16 ka, becoming warmer and drier (diets of 90–100% $C_4$ plants) roughly a millennium later (Smith et al., 2002) (Fig. 6d, t). Supporting this, DB's charcoals contain frost–tolerant taxa typical of high altitude or fynbos vegetation regimes today: *Cliffortia* spp., *Protea* spp., *Leucosidea sericea*, *Erica* spp., and *Rhamnus prinoides*. However, their diversity, and factor analysis results confirming high moisture availability (Fig. 6u), caution against overstating the ecological impoverishment of the pre–Holocene landscape (Esterhuysen, 1996). Faunal data from Sehonghong concur: its

taxonomically diverse terminal Pleistocene assemblage again includes smaller, browsing and canopy-loving antelope (Plug and Mitchell, 2008), with a $\delta^{13}C$ sediment value of −19.8‰ from Layer RBL-CLBRF (~15.7–15.2 ka; Pargeter et al., 2017) suggesting enhanced presence of $C_4$ plants, and thus markedly warmer conditions, than at the LGM (Loftus et al., 2015).

That warming did not last. Less than half a millennium later the Antarctic Cold Reversal (ACR; 14.6–13 ka) precipitated widespread and sustained cooling of the Southern Hemisphere (Pedro et al., 2016). Although Chase et al. (2011) argue that only latitudes south of 41°S were affected — something supported by recently synthesized SRZ pollen data suggesting that the warming trend initiated late in HS1 continued uninterrupted until ~13 ka (Scott et al., 2012) — evidence is mounting that in the Maloti-Drakensberg the ACR's timeframe was indeed cooler. In western Lesotho, a much lower $\delta^{13}C$ value of −10.4‰ from a zebra tooth at Ntloana Tšoana from Phase 5b of that site's sequence, which is dated at two-sigma by four determinations to ~14.5–13.4 ka, indicates a diet almost wholly composed of $C_3$ plants and, by extension, annual temperatures 6 °C lower than present (Smith et al., 2002). Assuming a plant-to-enamel apatite $\delta^{13}C$ fractionation of ~13‰ (Lee-Thorp et al., 1989), this precisely matches $\delta^{13}C$ analysis of sediments from the same portion of the site's stratigraphy (NT21–25, mean of −23.5‰, Roberts et al., 2013) (Fig. 5c).

Similar conditions seem likely at Sehonghong where Layer RF returned a $\delta^{13}C$ sediment value of −21.8‰ (Loftus et al., 2015) dated, at two-sigma, by several radiocarbon determinations to ~14.9–13.7 ka (Pargeter et al., 2017). Dates of ~14.7 and ~13.8 ka, on the other hand, run on soil organic matter for glacial moraines near the Escarpment's summit again provide only minimal ages (Mills et al., 2009b) (Fig. 5e). More securely, pollen, phytoliths, diatoms, and charcoals at Braamhoek signal wetter conditions (probably linked to northward shift of the westerlies; Fitchett et al., 2017b) from ~14 ka, peaking at ~13.6 or ~13.2 ka depending on the proxy; fynbos pollen indicates persistent cold (Finné et al., 2010; Norström et al., 2014) (Fig. 6a-b, m-o). A comparable picture emerges from pollen and a high silt/clay component in the basal stratum (Unit 9) of the Tsoaing sedimentary sequence in southwestern Lesotho, dated (at two-sigma) by a single radiocarbon determination to ~14.9–13.5 ka (Grab et al., 2005) (Fig. 6v). Aliwal North's pollen sequence also registers a moisture peak ~14.6 ka, as does that at Craigrossie 350 km further north (Scott et al., 2012). Drier conditions followed at both sites ~14 ka before a major resurgence of moisture at Craigrossie until ~13 ka (Fig. 6q–r). The consistency with which proxy archives register cool temperatures and high humidity between ~14.8 and ~13 ka may, we suspect, relate to the Maloti-Drakensberg's relatively high altitude since the ACR is strongly implicated in major episodes of glacier advance in other Southern Hemisphere mountain systems (e.g. Jomelli et al., 2017; Stansell et al., 2015).

### *4.4. The Pleistocene-Holocene transition and early Holocene 13–8.2 ka*

The period 13–11 ka is, in contrast, severely under-represented in our region's proxy archives, though evidence of dryness and variable cold is widespread elsewhere in the SRZ, perhaps in response to another abrupt Northern Hemisphere forcing event, the Younger Dryas (YD, ~13–11.5 ka). Reanalysis of the Wonderkrater pollen sequence (Truc et al., 2013), pollen signals from other southern Savanna Biome sites (Scott et al., 2012), and the cessation of speleothem formation at Cold Air Cave (Holmgren et al., 2003) suggest annual temperature depressions to LGM levels and sharply reduced summer rainfall at this time (Fig. 6i–l, x–z). Increased drought-tolerant pollen elements, lower $\delta^{13}C$ *n*-alkane values, and low magnetic susceptibility values suggesting reduced sedimentation at Braamhoek ~12.6–11.3 ka affirm this, with the persistence of fynbos pollen indicating that conditions remained cold (Norström et al., 2014) (Fig. 6a–b, m–p). A similar, if less pronounced, drying trend is evident in Aliwal North's pollen sequence (Scott et al., 2012) (Fig. 6q). In the Eastern Cape Drakensberg, charcoals dominated by the arid-adapted karroid taxon *Euryops* sp. from Layer 4 at Ravenscraig, dated to the very end of the YD (~11.8–11.2 ka), also fit this picture (Tusenius, 1989); an abundance of the moisture-loving Afromontane evergreen *Leucosidea sericea* in the underlying unit (Layer 5) does not contradict this since the associated date of ~12.4–11.3 ka (Opperman, 1987:147) is probably erroneous (see below).

The end of the YD stadial conventionally marks the interface between the Pleistocene and Holocene. Across the Maloti–-Drakensberg, as elsewhere, that transition saw major ecological changes on multiple timescales. On the coarsest analytical level, between ~11.5 and ~8.5 ka the region went from a cool, heavily grass-dominated open landscape to a warmer, more fragmented environment with more woody vegetation. Thus far, however, only the Caledon Valley provides a finer-grained image. At the very start of the Holocene (~11.5–11.1 ka), this area experienced mild to considerable warming relative to earlier phases of the Last Glacial-Interglacial transition. $\delta^{13}C$ sediment values at Ha Makotoko in western Lesotho are a key indicator and imply greater input of $C_4$ plants relative to those dating to the ACR at nearby Ntloana Tšoana (Roberts et al., 2013; HM14 cf. NT21–25; Fig. 5c–d); a mean $\delta^{13}C$ value of −2.3‰ ($n = 3$) from grazer teeth at the same site implies a ~60% $C_4$ grassland with temperatures only slightly cooler than present (Smith et al., 2002).

The same proxies then show a sudden cold reversal just after 11 ka (Fig. 5c), followed by high-magnitude oscillations between warmer and cooler temperatures that cannot be resolved closely in absolute time because of rapid sedimentation (at Ntloana Tšoana) combined with the effects of the early Holocene radiocarbon plateau (Roberts et al., 2013). A sharply cold episode is, however, clearly indicated ~10.5 ka when faunal $\delta^{13}C$ signals at Ha Makotoko imply an almost wholly $C_3$ grassland (Smith et al., 2002). The *Cliffortia*/*Protea*-dominated charcoal assemblage from Layer LB at Rose Cottage Cave (~11.1–10.6 ka) likewise suggests lower temperatures at this time. Relative to the YD, increasing frequencies of *Leucosidea sericea* in western Lesotho's charcoal record nevertheless indicate generally wetter conditions (Esterhuysen and Mitchell, 1997), as does the presence of *Xymalos monospora* (lemonwood) at Ntloana Tšoana ~10.4 ka (Deborah Costens, personal communication, 2011); today, this rainfall-demanding species only occurs east of the Escarpment (Palgrave, 1983:175).

Data are more plentiful after 10 ka. In western Lesotho faunal and sedimentary $\delta^{13}C$ records emphasize a warming trend with conditions perhaps only slightly cooler than today (Roberts et al., 2013, Fig. 5c–d) and grazer diets consisting of ~80% $C_4$ vegetation (Smith et al., 2002). At a third site in this sub-region, Tloutle, increased humidity is signalled ~9.9–9.5 ka (Layer GS) by *Podocarpus* charcoals, calcareous sinter (spring) deposits, and increased numbers of vleirats (*Otomys irroratus*), rodents that prefer densely wooded and streamside habitats (Esterhuysen and Mitchell, 1997; Plug, 1993) (Fig. 6e, u). Wetter conditions are also evident in sediments at Rose Cottage Cave (Butzer, 1984), where a more diverse range of large mammals testifies to increased environmental productivity (Plug and Engela, 1992). In particular, the presence of kudu (*Tragelaphus strepsiceros*) and both wildebeest taxa (*Connochaetes gnou*; *C. taurinus*) ~9.5–8.8 ka points to the expansion of sweeter $C_4$ grassland and a greater degree of canopy cover than later in the Holocene (Wadley, 2000a).

Other records also imply a generally ameliorating early Holocene climate. A decline in fynbos taxa and higher frequencies of

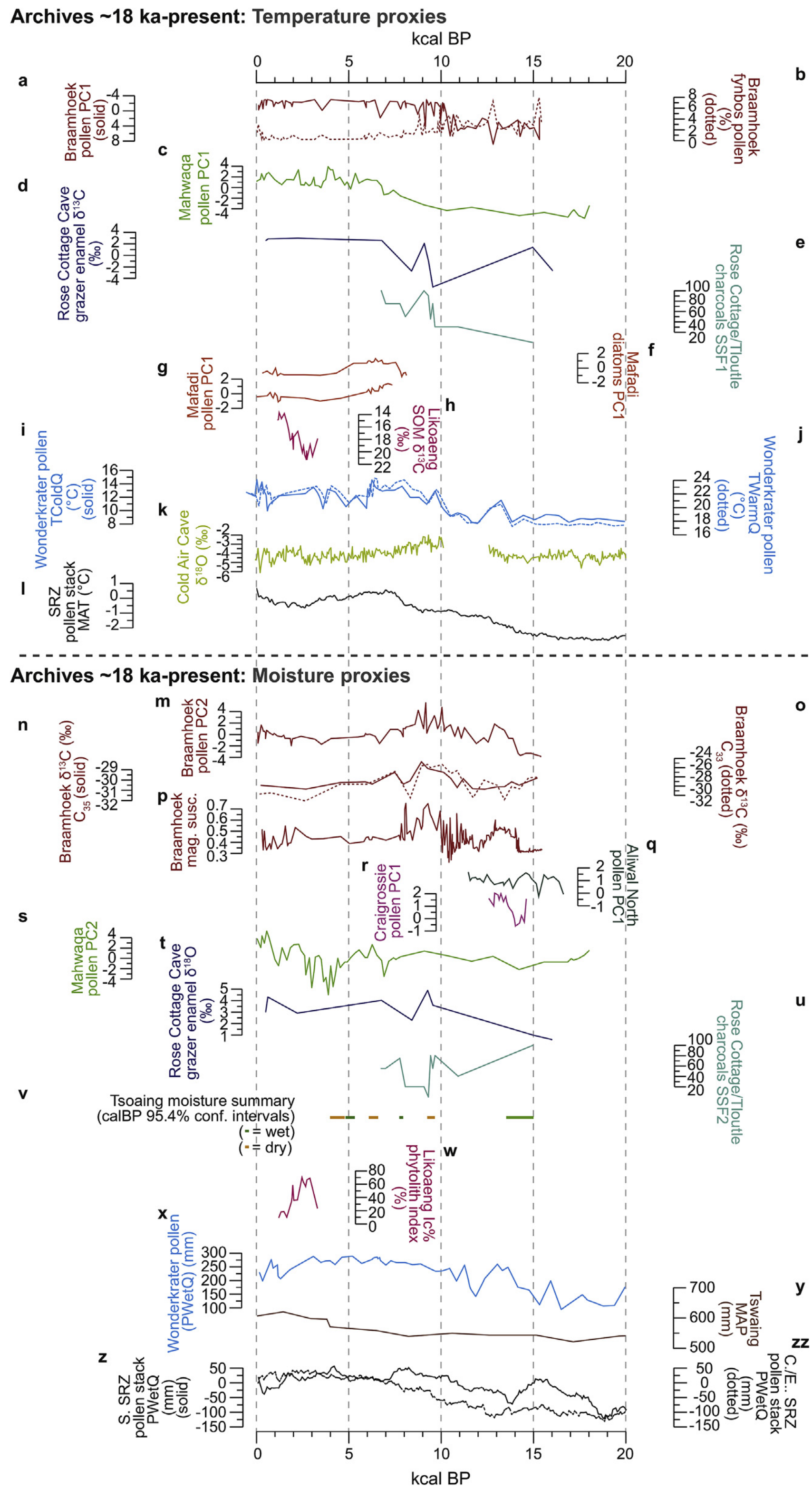


**Fig. 6.** Maloti-Drakensberg palaeoclimatic/environmental proxy data for archives younger than ~18 ka. Also shown are selected archives from the broader summer rainfall zone (SRZ). a: Braamhoek pollen first principal component (PC1) temperature index (Norström et al., 2014); b: Braamhoek frequency of fynbos pollen (Norström et al., 2014); c: Mahwaqa PC1 temperature index (Neumann et al., 2014); d: Rose Cottage Cave grazer tooth enamel $\delta^{13}C$ (Smith et al., 2002); e: combined Rose Cottage Cave and Tloutle charcoal standardized first factor (SSF1) temperature index (Esterhuysen et al., 1999); f: Mafadi diatoms PC1 temperature (/moisture) index (Fitchett et al., 2017a); g: Mafadi pollen PC1 temperature (/moisture) index (Fitchett et al., 2017a); h: Likoaeng sediment $\delta^{13}C$ (Parker et al., 2011); i: Wonderkrater pollen reconstructed mean temperature during the coldest quarter (of the year) (TColdQ) (Truc et al., 2013); j: Wonderkrater pollen reconstructed mean temperature during the warmest quarter (TWarmQ) (Truc et al., 2013); k: Cold Air Cave speleothems $\delta^{18}O$ (Holmgren et al., 2003); l: SRZ pollen stack reconstructed mean annual temperature (TmeanAnn) (relative to present-day) (Chevalier and Chase, 2015); m: Braamhoek pollen PC2 moisture index (Norström et al., 2014); n: Braamhoek $\delta^{13}C_{35}$ *n*-alkane biomarker (Norström et al., 2014); o: Braamhoek $\delta^{13}C_{33}$ *n*-alkane biomarker (Norström et al., 2014); p: Braamhoek sediment magnetic susceptibility (Norström et al., 2014); q: Aliwal North pollen PC1 moisture index (Scott et al., 2012); r: Craigrossie pollen PC1 moisture index (Scott et al., 2012); s: Mahwaqa PC2 moisture index (Neumann et al., 2014); t: Rose Cottage Cave grazer tooth enamel $\delta^{18}O$ (Smith et al., 2002); u: combined Rose Cottage Cave and Tloutle

grass species in the Braamhoek pollen sequence indicate increased temperatures and a shift toward a more strongly summer rainfall focus ~10.2–9.2 ka (Norström et al., 2014) (Fig. 6a–b, m). Within this overall trend, however, tooth enamel $\delta^{13}C$ (Smith et al., 2002) and factor analysis of charcoals at Rose Cottage (Esterhuysen et al., 1999; Esterhuysen and Smith, 2003) document a cooler episode ~9.5–9.3 ka (Layer Cm) that coincides with fluctuating conditions (Units 7–5) in both temperature and moisture in Tsoaing's phytolith and sedimentary record (Grab et al., 2005) (Fig. 6d–e, t–v). Partly overlapping with this, drier conditions ~9.5–8.8 ka in Rose Cottage's charcoal assemblage (Esterhuysen, 1996) are mirrored ~9.2–8.6 ka by changes in the xylem structure of *Olea* and *Rhus* charcoals at Bonawe in the Eastern Cape Drakensberg (Tusenius, 1989).

Other palaeoenvironmental archives are too coarsely resolved to offer useful comparisons with those from the Caledon Valley. However, a general early Holocene increase in small antelope and ground game after 11 ka may reflect increasing humidity and warmer temperatures around Sehonghong, just as at Rose Cottage Cave (Plug and Mitchell, 2008). That peat formation only started after 9 ka near Mokhotlong, northeast Lesotho, may nevertheless imply that conditions were not warm enough there before this (van Zinderen Bakker and Werger, 1974).

Charcoal assemblages in the Caledon Valley usefully remind us how varied conditions may have been. Consistently high frequencies of *Protea* spp. throughout the early Holocene levels at Ha Makotoko and Ntloana Tšoana suggest, for example, that temperatures in this part of Lesotho remained lower than those near Rose Cottage Cave just 40 km to the west. Conversely, 15 km to the southeast but closer to the Maloti Front Range, charcoals from Layer GS at Tloutle include not only *Podocarpus*, as previously noted, but also relatively high frequencies of *Olea africana*, *Leucosidea sericea*, and *Morella* (*Myrica) pilulifera*, taxa that imply local conditions sufficiently mesic to support patches of closed forest. Spatial variation between broadly contemporaneous charcoal assemblages is to be expected given micro-environmental variation in the availability of woody species and the impact of human fuel selection. Nevertheless, contrasts like these hint that climate change operated on finer spatiotemporal scales than is often appreciated. Multiproxy isotopic studies at the same shelters bear this problem out, with a solution demanding finer chronological control at more such sites (Roberts et al., 2013; Smith, 1997; Smith et al., 2002).

### 4.5. The middle Holocene 8.2–3.5 ka

In keeping with Walker et al. (2012), we take the sudden, short-lived, planet-wide 8.2 ka event as the start of the middle Holocene, while recognizing that its identification in southern Africa remains a challenge given the temporal resolution currently available. Mean $\delta^{13}C$ values of −2.6‰ at Rose Cottage Cave (Layer Pt-lower, $n = 2$) and −6.4‰ at Tloutle (Layer CSL-LR, basal Layer CSL-UP, $n = 3$) nevertheless imply a considerable shift toward a more $C_3$-rich grassland ~8.5–8.2 ka and ~8.2–7.8 ka respectively; relatively low mean $\delta^{18}O$ values (2.3‰ and 0.3‰ respectively) suggest cooler growing season temperatures (Smith et al., 2002). High frequencies of ice/snow-tolerant fragilariod diatoms from the lowest unit (MP5, ~8.1–7.6 ka) of the Mafadi core, southern Africa's highest wetland sample, likewise indicate harshly cold, but (locally?) wet conditions, with temperatures too low to support terrestrial plants (Fitchett et al., 2017a) (Fig. 6f).

Other proxies suggest that this colder episode was also significantly drier: Tloutle's CSL-LR charcoal assemblage, for example, lacks *Podocarpus* sp. but includes the only appearance of *Euphorbia* in the site's sequence; *Buddleia* and *Passerina montana* also increase in frequency (Esterhuysen and Mitchell, 1997). Oxygen isotope analysis of ostrich eggshell from the same layer confirms that conditions were more arid, while the accompanying fauna is less diverse than immediately above and below; bush-loving (common duiker) and water-dependent (common reedbuck, *Redunca arundinum*; mountain reedbuck, R. *fulvorufula*) ungulates are notable absentees (Mitchell, 2000). Drier conditions are also evident after 8.5 ka at Mahwaqa and Braamhoek (Fig. 6m, s) and in records from the central Free State (Neumann et al., 2014).

Across the region, temperatures remained relatively high until the start of the late Holocene Neoglacial ~3.5 ka, although moisture availability fluctuated. At Tloutle charcoals document a return to more mesic conditions ~7.9–6.7 ka, with *Podocarpus* again present (Esterhuysen and Mitchell, 1997). Consistent with this, faunal $\delta^{13}C$ values from the upper component of Rose Cottage's Layer Pt (~6.9–6.6 ka), like those from the bulk of CSL-UP at Tloutle, are positive (means of 2.7‰ and 2.5‰ respectively; $n = 6$ and 6) (Smith et al., 2002) (Fig. 6d). Although the single value from Tloutle Layer CCL (−2.7‰, ~7.3–6.7 ka) suggests that conditions did not remain static, grassland near Rose Cottage was probably 100% $C_4$ in composition by ~6.9–6.6 ka (Smith, 1997). Taking the period ~8.5–6.6 ka as a whole, that site's charcoals imply a relatively moist, warm climate associated with more wooded vegetation than present, including thermophilous species like *Grewia monticola* and *Acacia karoo* that are absent there today (Esterhuysen, 1996; Wadley et al., 1992). Microfaunal data agree that vegetation was denser than now (Avery, 1997), with high tooth enamel $\delta^{18}O$ values from both Rose Cottage and Tloutle suggesting increased moisture availability and warmer growing seasons (Smith, 1997; Smith et al., 2002) (Fig. 6t).

Vervet monkeys (*Chlorocebus pygerythrus*) took advantage of these changes to expand into the Caledon Valley, while records of roan antelope (*Hippotragus* cf. *equinus*) at Rose Cottage (~8.5–6.6 ka; Plug and Engela, 1992) and Fateng Tsa Pholo in western Lesotho (<7.7 ka; Shaw Badenhorst, personal communication, 2009) suggest good quality grass and/or expanding savanna with a climate warmer than present. Habitat changes associated with a warming climate may also be implicated in a major faunal turnover at Sehonghong ~8–6.5 ka where several medium and large grazers (springbok, blue antelope, blesbok) that had been present throughout the later Pleistocene now disappear. The restriction of heavily water-dependent common reedbuck to this part of the sequence also signals a wetter mid-Holocene landscape (Plug and Mitchell, 2008). Comparable changes (the loss of zebra, blesbok, *Hippotragus* sp., and an extinct caprine (Brink, 1999), plus a shift toward an ungulate fauna dominated by browsers or mixed-feeders) are evident above the Escarpment in the Eastern Cape Drakensberg, though less so below it where higher quality pasture was available (Opperman, 1987).

Other archives concur that mid-Holocene climates were generally warmer, if not always moister. For example, Unit 4 at Tsoaing records wetter conditions ~7.9–7.7 ka, followed by a drier phase ~6.7–6.1 ka (Grab et al., 2005) (Fig. 6v). A slight lowering of Asteraceae/Poaceae ratios (cf. Fitchett and Bamford, 2017) at Mafadi

charcoal standardized first factor (SSF2) moisture index (Esterhuysen et al., 1999); v: moisture summary of Tsoaing proxies (pollen, phytoliths, sedimentological) (Grab et al., 2005); w: Likoaeng phytolith 'climatic index' (Ic% = Pooid/Pooid + Chloridoid + Panicoid) (Parker et al., 2011); x: Wonderkrater pollen reconstructed mean precipitation during the wettest quarter (PWetQ) (Truc et al., 2013); y: Tswaing Impact Crater reconstructed mean annual precipitation (MAP) (Kristen et al., 2007); z: central/eastern SRZ pollen stack reconstructed mean precipitation during the wettest quarter (relative to present-day) (Chevalier and Chase, 2015); zz: northern SRZ pollen stack reconstructed mean precipitation during the wettest quarter (relative to present-day) (Chevalier and Chase, 2015).

could mark the presence of a summer rainfall regime not long after 7 ka, with reduced fragilariod and increased epiphytic diatom frequencies ~6.6–5.7 ka suggesting further warming into the Holocene Altithermal (Fig. 6f–g). Declining lake levels leading to the formation of a locally marshy environment imply that progressively drier conditions accompanied this (Fitchett et al., 2017a). Fluctuations in temperature and moisture are also indicated by the Sekhokong diatom record (Fitchett et al., 2016b), the Mahwaqa pollen sequence (Neumann et al., 2014), and a second one at Cathedral Peak closer to the Escarpment (Lodder et al., 2018), but the drier conditions implied by high frequencies of *Euryops* charcoals at Colwinton ~7.3–7.0 ka (Tusenius, 1989) are the only contribution from the Eastern Cape Drakensberg at this time.

The period between 6.0 ka and the onset of the Neoglacial is poorly known, though around 6 ka general circulation models predict drier conditions than present across the SRZ (Chevalier et al., 2017). Reduced precipitation may have resulted from shifts in the mean latitudinal position of the austral westerlies due to changes in winter sea-ice extent around Antarctica, given that a significant amount of the rain falling over southern Africa's interior results from systems formed when that westerly storm track interacts with tropical easterlies (Chevalier and Chase, 2015).

The Maloti-Drakensberg currently offers little to understanding this, although Leliehoek near Rose Cottage Cave is an exception. Its charcoal and faunal records (a proliferation of *Cliffortia linearifolia* scrub, increased numbers of vleirats, and the presence of common duiker) suggest that moist conditions prevailed ~5.9–4.9 ka (Esterhuysen et al., 1994). This fits well with the pulse of silt/clay accretion and highest rate of Holocene organic accumulation in Unit 2 at Tsoaing ~5.3–4.9 ka (Fig. 6v), which in turn conforms to a regional trend also evident in the central Free State and eastern Karoo (Grab et al., 2005; Scott, 1993; Scott and Nyakale, 2002). Conversely, the Sekhokong record in highland Lesotho shows the driest phase of its entire sequence down to 3.6 ka (Fitchett et al., 2016b), with drier conditions also evident after 5.6 ka at Cathedral Peak (Lodder et al., 2018) and Mahwaqa (Neumann et al., 2014) (Fig. 6s). The lack of conformity between these records and others for the period ~5–3 ka that do not suggest greater aridity in the SRZ may be due to local factors specific to their high altitude location (Chevalier and Chase, 2015).

### 4.6. The Neoglacial and after <3.5 ka

Several cold reversals of variable duration and intensity punctuated the later Holocene (<4.2 ka; Walker et al., 2012). The longest was the Neoglacial, a period of widespread cooling and humidity registered across much of southern Africa between ~3.5 and 2.0 ka (Nash and Meadows, 2012). The Caledon Valley provides little proxy evidence at this time, but high frequencies of *Olea africana* charcoals and low (or absent) frequencies of *Leucosidea sericea* and *Erica* spp. at Twyfelpoort and Mauermanshoek rockshelters signal relatively warm conditions ~3.9–3.0 ka (Backwell et al., 1996; Wadley, 2001). Faunal $\delta^{13}C$ values then imply a 100% $C_4$ grassland in the environs of Rose Cottage Cave ~2.3–2.1 ka (Smith et al., 2002; Wadley, 2000b) (Fig. 6d).

A more robust record comes from highland Lesotho. Taken as a whole, the period ~3.4–1.2 ka at Sekhokong was persistently cooler than before, but with continuous fluctuations in pollen and diatom assemblages. Wet phases are indicated ~3.26–3.19, ~3.05, and ~2.69–1.47 ka, with at least one drier episode before the last of these. The third, and most prolonged, wet event may have included more regular snowfalls (Fitchett et al., 2016b). Increases in sedge, *Aponogeton*, and grass pollen compared to that of the Asteraceae at Mahwaqa also signal more humid conditions after 3.5 ka (Neumann et al., 2014). On the other hand, the Mafadi profile shows little variation ~5.6–1.1 ka, though decreased frequencies of Cyperaceae and Asteraceae and increased numbers of ice/snow-tolerant *Fragilaria* and Apiaceae diatoms do suggest greater cold (Fitchett et al., 2017a) (Fig. 6f–g).

Finer detail comes from the open-air archaeological site of Likoaeng near Sehonghong. Here, phytoliths and $\delta^{13}C$ sediment values provide most of the evidence, amplified by charcoals and fauna (Mitchell et al., 2011; Parker et al., 2011). Before 3.0 ka the area supported grassland in which $C_4$ and $C_3$ taxa occurred in roughly equal proportions. Charcoals hint that conditions were cooler (*Erica* spp.) and drier (*Acacia* spp.) than present. Climate then cooled markedly, with $\delta^{13}C$ sediment values indicating a shift to $C_3$ pooid grassland at a scale best understood to imply a significant (≤400 m) downslope shift in vegetation and a temperature decrease of ~2.5 °C (Fig. 6h). Phytoliths and charcoals document the increased presence of cold-tolerant taxa like *Erica* spp., *Euryops* spp., *Protea* spp., and *Leucosidea sericea*. Increased numbers of *Labeobarbus aeneus* among the fish people caught may have been favoured by colder river temperatures, intensified perhaps by greater snowfall (and melt) (Mitchell et al., 2011), while high frequencies of pooid phytoliths suggest substantially increased moisture availability (Parker et al., 2011) (Fig. 6w). Renewed peat formation ~3.3–2.3 ka at Sani Top near the Escarpment's summit (Marker, 1994), palaeosol and overbank deposit formation at Kilchurn (~3.2–2.3 ka), and gully erosion at Tiffindell (~2.8–2.7 ka) (both in the Eastern Cape Drakensberg; Lewis, 2005) reinforce this. Analysis of charcoal xylem vessels at Bonawe agrees that conditions were less dry in the southeastern Maloti-Drakensberg ~3.3–2.8 ka than previously, but, consistent with the broader regional picture, drier again ~2.3–2.0 ka (Tusenius, 1989). Charcoals from Mhlwazini Cave and Collingham Shelter in the northern KwaZulu-Natal Drakensberg likewise identify decreased rainfall after 2.3 ka, with precipitation 40–80% higher than present before this (February, 1994).

Following the Neoglacial, the Maloti-Drakensberg experienced some of the warmest temperatures of the Holocene. At Likoaeng, a drier, warmer climate is evidenced ~2.1 ka by higher frequencies of $C_4$ phytoliths and $\delta^{13}C$ sediment values (−19.8‰ to −16.5‰) consistent with a mixed $C_3/C_4$ grassland (Fig. 6h, w). *Acacia* charcoals support this, with cool-loving plants absent (Mitchell et al., 2011; Parker et al., 2011). Across the SRZ, multiple records concur that a widespread arid episode occurred around 2000 years ago (Scott et al., 2012; Stager et al., 2013). Conditions became even warmer and drier 1.6–1.0 ka (Parker et al., 2011) with the highest $\delta^{13}C$ sediment values recorded in the Likoaeng sequence indicating an upper Senqu Valley heavily dominated by $C_4$ taxa; frequencies of arid-adapted chloridoid $C_4$ phytoliths also peak, but $C_3$ pooid counts are at their lowest ever (Fig. 6h, w). Below the Escarpment, charcoal vessel diameters at Collingham Shelter agree that conditions were relatively dry ~1.3–1.0 ka (February, 1994).

These drier, warmer conditions likely represent the local impact of another widely recognized climatic episode, the Medieval Climatic Anomaly (MCA, ~1.4–0.65 ka). Both it and the ensuing Little Ice Age (LIA, ~0.65–0.15 ka) register in several other regional archives, including peat deposits at Tlaeeng Pass, northern Lesotho (Hanvey and Marker, 1992), the Craigrossie pollen sequence in the easternmost Free State (Scott, 1989), and $\delta^{13}C$ sediment values at open-air sampling locations near Sehonghong (Julia Lee-Thorp, personal communication, 2016). In lowland Lesotho a single faunal $\delta^{13}C$ value (−9.6‰) from Tloutle (with a very low associated $\delta^{18}O$ value, −0.8‰) documents a significantly colder episode that may equate to the start of the LIA (Smith, 1997). Nevertheless, at Rose Cottage Cave, micromammals, charcoals, and $\delta^{13}C$ and $\delta^{18}O$ values from grazers suggest that climate was still warmer than present ~0.7–0.5 ka with an overwhelmingly $C_4$ grassland (Avery,

1997; Smith et al., 2002; Wadley, 1997) (Fig. 6d–e, t). Thereafter, however, reduced charcoal diversity and the presence of cold-tolerant *Protea* spp. (Wadley, 1997), along with lower *Olea* frequencies at Mauermanshoek and Twyfelpoort (Backwell et al., 1996; Wadley, 2001), signal cooler conditions ~0.5–0.2 ka.

Other observations are more difficult to correlate with the MCA or the LIA because of low temporal resolution and because conditions did not remain static within either episode (Stager et al., 2013:118). For example, identifications of a hippotragine antelope and vervet monkey at Lithakong, between the Front and Central Ranges of the Maloti, may imply warmer conditions (with more trees along river valleys) but are not more precisely dated than to some time within the last 1000 years (Brink, 2012). Highland sediment cores document cooler and/or wetter conditions in the early part of this period, with drier ones thereafter, but chronologies are again too imprecise to identify either episode with part or all of the MCA or LIA (Fitchett et al., 2016b, 2017a; Neumann et al., 2014). Similarly, while charcoal data at Ravenscraig ~0.5–0.3 ka (Tusenius, 1989) and Mhlwazini ~0.6–0.2 ka (February, 1994) imply cooler/moister conditions linkable to the LIA, wetter conditions at Colwinton ~2.0–1.7 and ~0.9–0.7 ka (Tusenius, 1989) are more difficult to assess. Neither these episodes, nor the cool, moist conditions suggested by pronival rampart formation on the slopes of Thabana Ntlenyana after 1.7 ka (Grab and Mills, 2011), are yet easily reconcilable with other regional proxies.

## 5. Regional occupation trends in archaeological radiocarbon data

Archaeologists have long been interested in how changing climatic conditions affected people living in the Maloti-Drakensberg. This has encouraged collection and analysis of many of the palaeoenvironmental proxies discussed above, as well as the development of ideas about seasonal mobility over the landscape and its social consequences that remain relevant today (e.g. Carter, 1970, 1976, 1978). One strategy for investigating these issues uses radiocarbon dates to establish when people were present in a particular locality (e.g. Manning and Timpson, 2014; Méndez et al., 2015; Williams et al., 2015; cf. Kinahan, 2016). At the time of writing, 344 archaeological radiocarbon dates are available from the Maloti-Drakensberg region. Here, we omit 19 of these because their 2σ calibrated range is out of stratigraphic sequence or they returned ages of “modern” or “infinite”. While still small compared to the sample sizes recommended by Williams (2012), we employ the remaining 325 dates to identify patterns in human occupation that may, provisionally, relate to the climatic and environmental shifts discussed above (Supplementary Table 3). In doing this, we acknowledge that variation in the materials sampled and the pretreatment protocols applied to remove contaminants may affect the accuracy and precision of individual dates, that techniques have evolved over the past half-century, and that not all sites have been dated with equal thoroughness.

To examine region-wide patterning, Fig. 7 presents a summed probability distribution (SPD) of our quality-controlled dataset of 325 dates against a more conservative histogram of dates binned into 1000-year intervals. The major climatic phases discussed above are also shown. Low radiocarbon date frequencies characterize the late Pleistocene, with clear spikes at the onset of the LGM (~25–24 ka) and during the ACR (~14 ka). Following each comes a trough during which few or no dates have been generated for the region; these troughs correspond to the height of the LGM/early HS1 (~23–17 ka) and the YD (~13–11.5 ka) respectively (Fig. 7). As discussed below, we strongly suspect that the intense cold registered in myriad proxy datasets at these times discouraged hunter-gatherer settlement of the Maloti-Drakensberg region as a whole. Whether the correspondence between earlier Heinrich Stadials (e.g. HS2–5) and earlier troughs in the SPD (Fig. 7) hints that similar dynamics recurred throughout the Late Pleistocene must remain speculative pending more dates from these time-depths.

Both the frequencies of dates and their temporal variability increase in the early Holocene, when regional temperatures and moisture availability rose steeply, with histogram and SPD peaks at 11–10 ka and 10–9 ka respectively. Frequencies then decline into the middle Holocene, with the histogram reducing gradually but the SPD exhibiting sharp fluctuations. Peaks in the latter are evident ~8.5–8.3, ~8.1–7.5, ~7.3–6.5, and ~6.0–4.9 ka, phases when the data summarized above suggest that humidity was high. Intervening troughs ~9.5–8.6, ~8.3–8.1, ~7.5–7.3, ~6.5–6.0, and ~4.9–4.0 ka correspond to drier periods (Fig. 7). The downward middle Holocene trends of both plots bottom out ~5–4 ka, coincident with the late Altithermal when most Maloti-Drakensberg records signal heightened aridity (except in the eastern Free State; see below). Radiocarbon date frequencies then rise dramatically in the late Holocene, beginning ~4 ka and accelerating sharply shortly after the onset of the cool, wet Neoglacial. Relative to their previous high in the millennium 11–10 ka, histogram values more than double between 4 and 2 ka, peaking at more than triple for the last millennium. The SPD provides sharper resolution, with late Holocene peaks ~3.0–2.7, ~2.3–1.5, ~1.3–0.9, and 0.8–0.3 ka (the latter is the record's highest) separated by short-lived but substantial declines (Fig. 7).

To see whether radiocarbon dates provide insights into variability in human settlement preferences for different parts of the Maloti-Drakensberg, Fig. 8 breaks the data down by sub-region. Because sample sizes are much smaller, only millennium-binned histograms are used rather than SPDs. Stark differences are apparent, most strikingly perhaps the longevity, continuity, and intensity of human occupation in highland Lesotho relative to other sub-regions. We stress that this is not an artefact of research bias, since other sub-regions have received comparable levels of archaeological investigation and dating, particularly the northern KwaZulu-Natal Drakensberg and lowland Lesotho.

Our earliest radiocarbon dates come from Melikane in highland Lesotho, which has a series of mid-MIS 3-aged determinations between ~48 and 36 ka (constrained by rigorous acid-base-wet oxidation stepped combustion pretreatment and Bayesian modelling to ~43–38 ka (Stewart et al., 2012:50)). Lowland Lesotho is the only other sub-region registering human occupation in this timeframe, with several dates concentrated in a single millennium ~44–43 ka. Other sub-regions come online after ~36 ka, first the eastern Free State (Rose Cottage Cave) followed two millennia later (~34 ka) by the Eastern Cape Drakensberg (Strathalan B) (Fig. 8). Meanwhile, occupation continued in highland Lesotho, with Sehonghong having a series of tightly constrained late MIS 3 levels ~35–29 ka (Loftus et al., 2015; Pargeter et al., 2017).

After a strong highland Lesotho pulse centred on ~24 ka, the Maloti-Drakensberg witnessed very little human activity across the LGM. Despite ephemeral signals at both Rose Cottage Cave and Sehonghong ~22.2–20.8 ka (Layers G and BAS respectively) and again ~19.3–18.6 ka (Layers Wa and BAS respectively) (Pargeter et al., 2017), sustained re-occupation only began after 16.5 ka (Rose Cottage) and 15.7 ka (Sehonghong). The situation at Rose Cottage still requires clarification since Layer DB is currently dated to ~16.5–15.6 *and* ~15.4–14.3 ka, but at Sehonghong two distinct occupation pulses are definitely evident. The first (~16–15 ka) coincides with markedly warmer temperatures relative to pre-LGM conditions, while the second (~14.8–13.7 ka) accords with the earlier part of the ACR and is also evident in lowland Lesotho. Both the Eastern Cape and the KwaZulu-Natal Drakensberg, on the other hand, appear to have been unoccupied throughout this period.

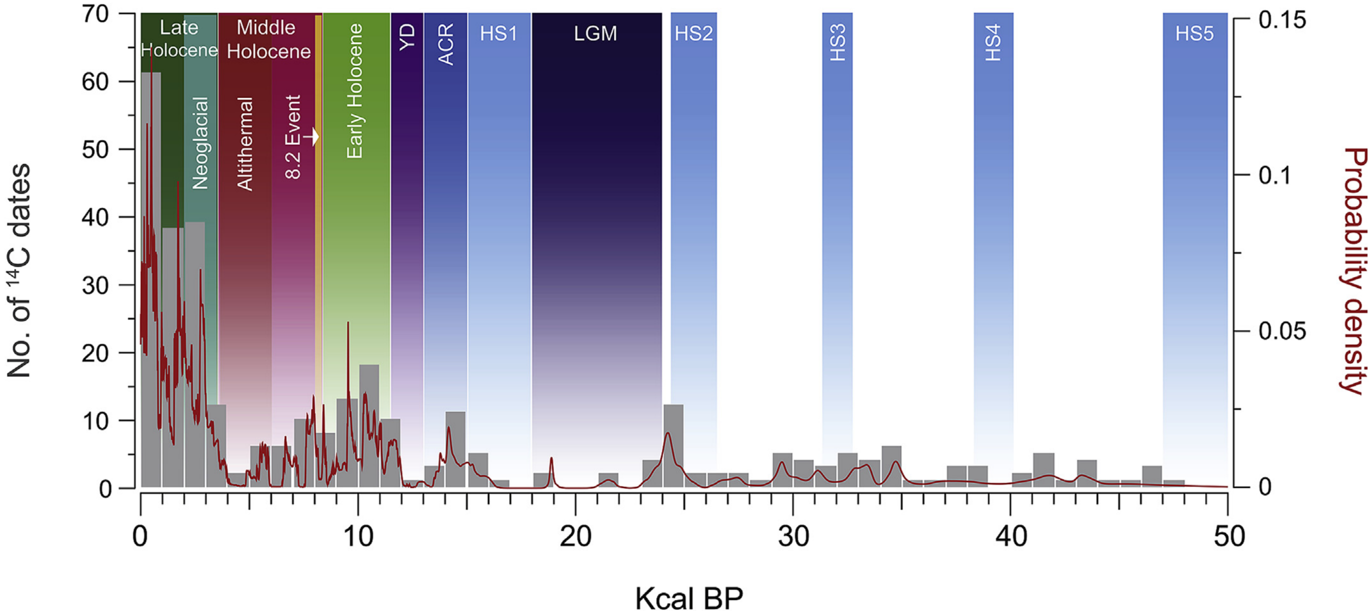


**Fig. 7.** Summed probability distribution (red) of the full quality-controlled database of 325 radiocarbon dates available for the Maloti-Drakensberg against a histogram of dates per millennium (grey). Also shown are the major climatic phases discussed in this paper.

The return of globally colder conditions during the YD posed further challenges to Maloti-Drakensberg hunter-gatherers. Except for a stratigraphically thin context at Sehonghong (Layer BARF), poorly constrained by a single conventional date to ~13.4–12.6 ka, neither highland Lesotho nor the eastern Free State has yet delivered evidence of occupation at this time (Fig. 8). The same applies to the Eastern Cape Drakensberg, where a determination calibrated

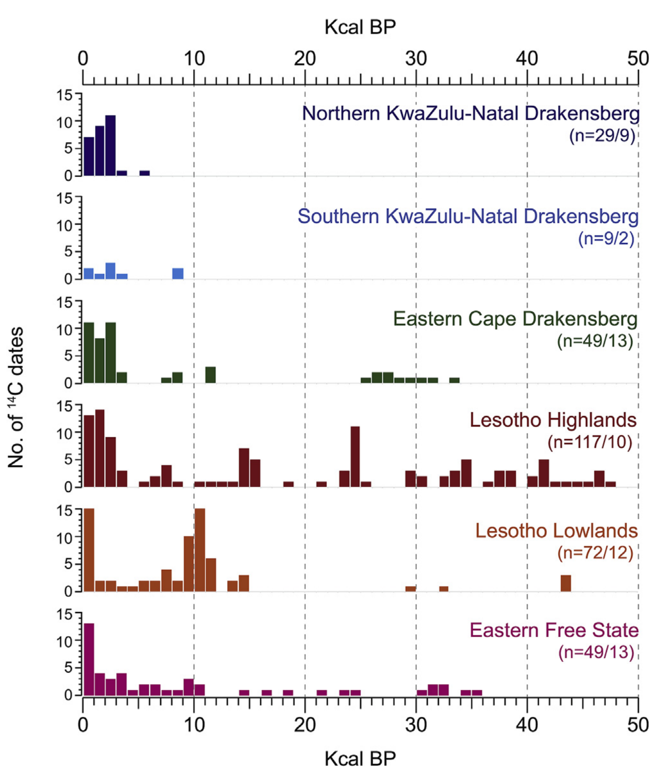


**Fig. 8.** Comparison of radiocarbon date frequencies for the Maloti-Drakensberg's six major sub-regions shown as histograms of dates per millennium. The number of dates/sites for each sub-region is also provided.

to ~12.4–11.3 ka for a Robberg assemblage at Ravenscraig (Opperman, 1987) is, we suspect, erroneously young given the tightness with which this industry is now dated in Lesotho (cf. Mitchell and Arthur, 2014:227). There, however, Ha Makotoko does clearly document human presence just before the YD ended (Mitchell and Arthur, 2014).

Subsequently, an upturn in occupation is quickly evident in several sequences, with both Rose Cottage and Sehonghong documenting multiple visits ~11.2–10.2 ka and ~11.5–10.5 ka respectively. Only in lowland Lesotho, however, is significant occupation evident in this time frame *and* the following millennium 10.5–9.5 ka (Fig. 8). Thereafter, several more sites return dates, with occupation signalled from both sides of the Caledon River ~9.6–8.2 ka, as well as the Eastern Cape Drakensberg (Bonawe, Strathalan A, and Te Vrede, but probably also undated assemblages from Ravenscraig Layers 3 and 4 and Colwinton Layer 6; Opperman, 1987, 1996). Brief (?) occupations ~8.5–8.3 ka at Belleview and Good Hope represent the first sign of human presence along the uKhahlamba-Drakensberg Escarpment since well before the LGM (Cable et al., 1980; Carter, 1978).

In lowland Lesotho thick aeolian and fluvial sediments deposited above extensive sequences of early Holocene occupation in the Metolong area soon after ~9.5–9.1 ka mark the start of a multi-millennial break in the use of these sites. Dates from Rose Cottage Cave's Pt Layer also imply an occupation hiatus after ~8.5–8.2 ka, while KwaZulu-Natal's southern Drakensberg was seemingly abandoned for several millennia. However, neither the timing nor the scale of these changes are readily (solely) explained by the 8.2 ka event, for which occupational evidence is most evident in lowland and highland Lesotho, followed by further activity at Rose Cottage Cave ~7.7–7.6 ka (Fig. 8). Thereafter, generally warmer, moister conditions saw further occupation in these three areas and probably also in the Eastern Cape Drakensberg, where several relevant contexts remain undated (Opperman, 1987).

Perhaps significantly, human presence has yet to be registered in the Caledon Valley during the drier climatic phase registered at Tsoaing ~6.7–6.1 ka, although people were present at Rose Cottage just before this and at Tloutle both before and after. Elsewhere, only Sehonghong (highland Lesotho) shows activity at this time (Layer

GWA, ~6.9–6.5 ka), which the Mahwaqa core suggests was warmer (Neumann et al., 2014). Generally drier mid-Holocene conditions ~6.0–3.5 ka (cf. Chevalier et al., 2017) are then associated with only minimal evidence of people outside the eastern Free State (at Liphofung on the eastern edge of the Caledon Valley and in the basal occupation at Diamond 1, the oldest signal yet known from the northern KwaZulu-Natal Drakensberg). Across the region, the mid-Holocene Altithermal may thus have been generally antithetical to human presence (Fig. 8), although, as our discussion above suggests, its climate was certainly not unvarying, particularly with regard to moisture availability (Fig. 5m, o; Fig. 6s, w).

In sharp contrast, the considerably cooler and wetter Neoglacial is strongly represented in archaeological records from most sub-regions (Fig. 8). Lowland Lesotho is an exception, but the presence of people in the ecologically similar eastern Free State suggests that this reflects site taphonomy and/or archaeological survey. Relevant here is a river-cut section along the Phuthiatsana River that documents deposition of 2.6 m of sediment between 4.8 and 3.4 ka, implying erosion and sedimentation on a scale sufficient to remove/cover up open-air sites and affect access to some rockshelters (Charles Arthur, personal communication, 2016). Archaeologists' preference for excavating at the very largest sites rather than smaller ones creates a further bias (Mitchell, 1994).

Heavy occupation is also evident immediately after the Neoglacial ~2.0–1.6 ka, with the Medieval Climatic Anomaly (~1.4–0.65 ka) appearing to have had little effect, notwithstanding the drier conditions signalled at Collingham and in the Senqu Valley. Occupation is evident in KwaZulu-Natal's southern Drakensberg, the Eastern Cape Drakensberg, highland Lesotho, lowland Lesotho (but by rock paintings, not excavated assemblages; Bonneau et al., 2017), and the eastern Free State (Fig. 8). However, the northern KwaZulu-Natal Drakensberg seems to have been completely abandoned, perhaps because local hunter-gatherers moved downslope toward farming communities in the central Thukela Basin in order to access metal, grain, and other desirables (Mazel, 2009). Its subsequent reoccupation may reflect disruption — and expansion into higher-lying grasslands — of those same agropastoralists as the Little Ice Age began ~0.65 ka (Whitelaw, 2015). Hunter-gatherers relocated into the foothills of the Escarpment, and then into the Escarpment itself, presumably to remove themselves from encroaching farmers (Mazel, 2009).

Discerning chronological detail during the last several centuries using radiocarbon dates is handicapped by the shortness of the time-scale involved and the well-known wiggles of the calibration curve. At a broad level, however, the return to generally colder, wetter conditions is associated with increased evidence of occupation in all sub-regions bar, perhaps, KwaZulu-Natal's southern Drakensberg, where neither Belleview nor Good Hope preserve well-defined occupations.

## 6. Human-environment dynamics in the Maloti-Drakensberg

Drawing together the palaeoclimatic and occupational data reviewed above, we now explore macro-regional trends in human-environment dynamics across the Maloti-Drakensberg region. We begin by asking which climatic conditions coincided with evidence of definite human presence. While our radiocarbon dataset is not yet large enough to make statistically robust inferences regarding palaeodemographic trends and our archaeological data remain skewed towards rockshelters, we feel confident that clear patterns are emerging as to the climatic conditions in which human settlement was consistent enough to produce spikes in radiocarbon date frequencies.

Elsewhere we have hypothesized that phases of intensified human presence in the Maloti-Drakensberg should correlate with regional proxy evidence indicative of warming and/or aridity (Mitchell, 1990; Stewart et al., 2012). The logical basis for this is twofold: first, this upland region is southern Africa's coldest zone, with present-day Effective Temperatures (ET) falling below 14 °C almost everywhere (Stewart and Mitchell, in press); and second, it possesses some of the subcontinent's most predictable and abundant resources due to its high rainfall and low evapotranspiration. It follows that the Maloti-Drakensberg might only have become attractive or viable for human settlement when temperatures in the wider region were relatively high and/or freshwater, and the plants and animals dependent on it, limited. The Maloti-Drakensberg's 'core' — Lesotho's highlands (and, to a lesser extent, lowlands) — is especially important in this regard due to its consistently productive and water-rich Senqu catchment (Stewart et al., 2016). Several episodes of intensified highland occupation plausibly correlate with such phases.

Specifically, the intensive mid-MIS 3 pulse at Melikane ~43–38 ka overlaps neatly with well-dated evidence for widespread aridity-linked colluviation in the KwaZulu-Natal Midlands (Stewart et al., 2016; Temme et al., 2008). Humans were again living at Melikane when phytolith and charcoal evidence suggest a massive reduction of woodland during the early LGM ~24 ka, an occupation pulse also registered at nearby Sehonghong. Turning to the Holocene, multiple proxy archives (e.g. Esterhuysen and Mitchell, 1997; Fitchett et al., 2017a; Smith et al., 2002) identify sudden and severe drying that may be linked to the 8.2 ka event. Human occupation at and immediately after this is well-represented in both highland (Sehonghong) and lowland (Tloutle) Lesotho. Slightly later, the arid and warm phase registered at Tsoaing and Mahwaqa ~7–6 ka again sees Sehonghong intensively inhabited. Strikingly, each of these pulses correlates with occupational hiatuses at various lower altitude sites, including several in other Maloti-Drakensberg sub-regions, raising the prospect that Lesotho's mountain core did indeed serve a refugium-like function for people at such times.

Yet our data also show that the climatic conditions corresponding to what seem to be the most intensive occupational pulses were more diverse than we have previously predicted. At times, for example, regional climatic instability itself may have played a more central role. We have pointed out that Melikane's mid-MIS 3 pulse is coeval with deposition of aeolian deposits in the far northern Maloti-Drakensberg (Telfer et al., 2012, 2014) and of thick colluvial mantles both here (Temme et al., 2008) and across KwaZulu-Natal (Botha and Partridge, 2000; Clarke et al., 2003). However, in all cases these aeolian and colluvial sediments are interspersed with multiple palaeosols suggesting reversions to more humid conditions that allowed greater vegetation cover and pedogenesis. This is echoed at Melikane itself, where climatic volatility is strongly suggested by diverse geogenic inputs into these deposits and signs of intense chemical weathering (Stewart et al., 2012). Similarly, a wide range of proxy data from the Caledon Valley suggest pronounced climatic flux during the early Holocene (~11.5–9.5 ka), with large, rapid swings in temperature and available moisture (Esterhuysen and Smith, 2003; Roberts et al., 2013; Smith et al., 2002). Nevertheless, this period saw dense occupations at numerous sites along drainages of the Maloti Front Range, attesting to population stability in this area when climate was anything but. Lesotho's highlands also witnessed human presence in the first half of this interval, with Sehonghong occupied between ~11.5 and ~10.5 ka (Mitchell, 1996a). In fact, these volatile early Holocene millennia yield the highest frequencies of radiocarbon dates of any time before the Neoglacial (Fig. 7).

Conceivably, it was the pace and magnitude of climatic and associated ecological changes rather than any specific event that underwrote regional settlement decisions during the early Holocene and mid-MIS 3. What might have drawn foragers into the

Maloti-Drakensberg's mountain core at such times? Though the region's pronounced seasonality and ruggedness make it logistically taxing, its attractions are considerable. They include greater resource diversity per unit area of terrain, reliable supplies of firewood, plant foods, and medicines, opportunities for summer hunting windfalls, abundant rockshelters, high quality toolstone, rich riverine faunas, and, of course, freshwater (Fig. 9). The latter — supplied by orographic rainfall and snowmelt and regulated by high altitude bog systems — may have been especially vital when recurrent shifts in precipitation and/or evapotranspiration resulted in unpredictable aquifer conditions further downslope (Stewart et al., 2016). The proxy data reviewed above suggest remarkable consistency in water availability as evidenced by the persistence of moisture-loving vegetation throughout virtually the entire period under investigation. We suggest that this may partly account for the consistency with which highland Lesotho registers human occupation relative to other sub-regions (Fig. 8).

More surprisingly, several of the most pronounced radiocarbon peaks in Fig. 8 are associated with regional conditions that climate proxies suggest were cool to cold. Indeed, three of the four dry pulses with human occupation just listed — mid-MIS 3 (after ~42 ka), the early LGM (~24 ka), and the 8.2 ka event — were also characterized by negative temperature excursions. To this we can add the ACR and Neoglacial, both of which were cool (though humid) and associated with radiocarbon peaks (Fig. 7). This seems counterintuitive; why would foragers have enhanced their use of higher altitudes at times when lower ambient temperatures increased metabolic requirements, exposure to cold stress, the extent and duration of snow cover, and the downslope movement of nutrient-poor Afroalpine vegetation belts? The answer, we believe, is that this pattern does not relate to an intensified upland presence, but rather to changes in how pre-existing populations organized themselves in relation to the highland landscape and its resources. Specifically, declines in terrestrial productivity accompanying expansions of Afroalpine grass and fynbos elements likely limited the availability of plant food staples, narrowed windows of reliable hunting, and raised overall terrestrial resource search costs. Groups already present in the area would have responded by assuming even more valley-centred settlement-subsistence foci (Stewart and Mitchell, in press). *Inter alia*, this entailed intensified use of large rockshelters, which likely produced the cold-phase radiocarbon spikes that we have detected, and greater procurement of fish, certain taxa of which flourish in colder waters (Mitchell et al., 2011). The latter represents a conspicuous dietary shift to which we return below.

Are there specific climatic phases when we can definitively say that the Maloti-Drakensberg region was abandoned? Previous assumptions of gaps across the Pleistocene-Holocene transition and the Neoglacial have been falsified by the discovery and dating of new sites (Mitchell, 1996a; Mitchell et al., 2011), meaning that extreme caution must be exercised to avoid over-extrapolating demographic patterning from currently available radiocarbon ages. Moreover, given the time-depth across which humans have exhibited a high degree of adaptive resilience and behavioural plasticity (Wadley, 2015), we suspect that permanent human occupation of certain parts of the Maloti-Drakensberg (e.g. highland Lesotho) was the norm for much of the later Pleistocene. However, two chronological gaps do seem likely to eventually

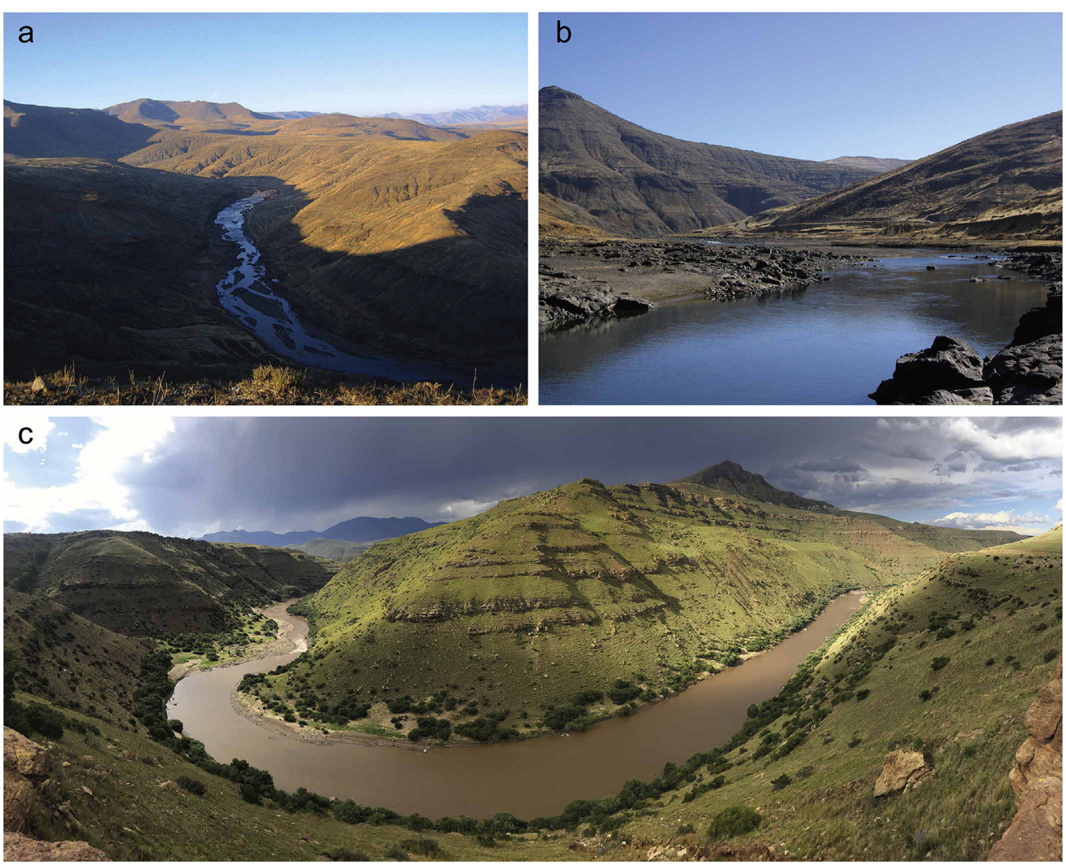


**Fig. 9.** Three views of the upper Orange-Senqu River fluvial network in the mountain core of highland Lesotho. a: looking south along the Orange-Senqu between Makunyapane and Mashai; b: looking south along the Orange-Senqu between Sehonghong and Tebalo; c: looking panoramically east and west along the Orange-Senqu between Patlong and Seapa. All photos by BAS.

become demonstrable population lulls, namely the apexes of the LGM and the YD (Fig. 7). Our review of relevant proxy data suggests that low terrestrial evapotranspiration during rainfall-poor phases like the LGM and YD offset losses in available moisture. Nevertheless, severe temperature depressions themselves, though rare, probably pushed resource availabilities (plant foods, game, fuel), socioeconomic scheduling (subsistence organization, social network maintenance), and/or technological capacities (clothing, shelter, exchange items) beyond adaptive thresholds, resulting in genuine regional demographic collapses.

Dispersal is, of course, only one potential response available to hunter-gatherers faced with resource (or other) stress. More often, Maloti-Drakensberg foragers were probably able to adjust their diets, technologies, land-use, and social practices on a local basis. Which of those responses can most clearly help us elucidate human-environment dynamics in the Maloti-Drakensberg? At present, the most striking evidence for subsistence reorientation is the recurrent increase in fish bone frequencies in highland Lesotho sites during cold phases (the early LGM- and ACR-aged levels of Sehonghong and the Neoglacial levels at Likoaeng) (Stewart and Mitchell, in press). As mentioned above, this expansion of dietary breadth was likely a response to the increased costs of finding game as reduced temperatures and greater winter precipitation simultaneously lowered Afroalpine vegetation belts, increased snowfall, and enhanced riverine productivity. Though less pronounced, other instances of dietary intensification coincide with some of the abrupt environmental changes reviewed here: increased grindstone frequencies suggestive of heavy grass seed processing in the late Pleistocene levels of Ntloana Tšoana (lowland Lesotho); a spike in freshwater mollusc shells close to the 8.2 ka event at Tloutle (lowland Lesotho); and an abundance of frog remains in a MCA-aged layer at Colwinton (Eastern Cape Drakensberg) (Mitchell, 2000; Opperman, 1987; Plug, 1993).

As elsewhere in southern Africa, major transitions between lithic techno-complexes in the Maloti-Drakensberg match climate change events only weakly and sometimes not at all (Deacon, 1984), but smaller-scale technological adjustments do often track such shifts. One consistent phenomenon is an uptick in bipolar core reduction during arid-/cold-induced phases of reduced terrestrial productivity, including mid-MIS 3 (<42 ka) at Melikane, the early LGM there and at Sehonghong, the ACR at Sehonghong, the ~9.5–9.3 ka dry/cool interval at Ha Makotoko and Tloutle, and ~8.2 ka at Tloutle (Mitchell, 2000; Pargeter et al., 2017; Stewart et al., 2012). Bipolar technology was employed at numerous times and places throughout prehistory in apparent efforts to extend the use-lives of both cores and tools (Hiscock, 2015). That enhanced use of bipolar techniques in the Maloti-Drakensberg is independent of any change in the dominance of fine-grained rocks likewise strongly suggests that these shifts reflect raw material economizing behaviours undertaken to alleviate scheduling conflicts and time-stress (Mitchell, 2000). Indeed, technological reorganizations hint at broader changes in forager land-use and settlement patterns. We have already suggested that valley-focused settlement arrangements during the early LGM, ACR, and Neoglacial likely encouraged more intensive occupation that resulted in our cold-phase radiocarbon peaks. Supporting evidence comes from consistently high artefact densities in the relevant levels of Sehonghong and Likoaeng (Pargeter et al., 2017; Stewart and Mitchell, in press), as well as in the ~8.2 ka deposits at Tloutle (Mitchell, 2000), suggesting settlement regimes in which site visits were more frequent, lasted longer, or involved larger groups, perhaps as resource patches became more fragmented in space and time. Amplified human signals in rockshelters/caves during colder climatic phases of the late Quaternary have also been documented far beyond southern Africa (e.g. Conard et al., 2012).

The variables underwriting at least some of these subsistence-settlement and technological shifts were almost certainly *not* strictly resource-related. Many of the phases of climatic downturn and resource stress reviewed here see tantalizing hints of enhanced social networking on various levels, ranging from long-distance importation of marine shell and ostrich eggshell beads (Mitchell, 1996b, 2000) to tentative evidence for group aggregations involving more formalized uses of space (Mitchell, 2000; Ouzman and Wadley, 1997) and, in at least one instance, scheduling to take advantage of seasonal resource bonanzas (Mitchell et al., 2011). If their purpose was to strengthen intra- and inter-group cohesion and co-operation during uncertain times, then such social strategies may have entailed an enhanced ritual component. Circumstantial supporting evidence may come from increased frequencies of mineral pigments in some sites (e.g. Mitchell, 1996a), but more certainly from phases of intensified production of rock art only now beginning to be recognized by directly dating the paintings themselves (Bonneau et al., 2017).

## 7. Conclusions and future prospects

We have reviewed the current state of knowledge regarding palaeoclimatic and palaeoenvironmental changes in southern Africa's highest region over the past 50 kyr. We also employed a quality-controlled dataset of 325 archaeological radiocarbon dates to preliminarily explore patterning in human occupation across it. Integrating these climatic and chronological data, we have attempted to identify the climatic contexts in which human presence was strongest (weakest), to understand what attracted (dissuaded) foragers from inhabiting the Maloti-Drakensberg at such times, and to explore some of the clearest examples of human-environment dynamics in this unique mountain zone. The region's altitudinal reach renders it particularly sensitive to climate changes, which, together with associated shifts in local environments, were considerable and complex. High amplitude and sometimes rapid shifts are evident not only within phases known for their volatility, such as MIS 3, but also at numerous other occasions during the later Pleistocene and Holocene.

Despite this variability, diverse proxy indicators suggest that parts of the region enjoyed a substantial degree of habitat resilience. Resources and the human populations dependent on them appear to have been particularly stable in Lesotho's mountain ‘core’, where the Orange-Senqu fluvial network and other similarly well-protected and resource-rich deep valley systems offered foragers greater predictability than many other inland regions. Our radiocarbon data tentatively suggest two instances of intensified human presence in Lesotho coinciding with regional instability — mid-MIS 3 and the early Holocene — complicating and enriching our previous expectations regarding the climatic contexts of upland exploitation. Importantly, the region's proxy data also reinforce a picture emerging across much of the SRZ of cold maxima having been characterized by greater moisture availability than previously postulated on account of reduced evapotranspiration, a compensation that was surely more pronounced in the Maloti-Drakensberg than anywhere else on the subcontinent. Moreover, cold-phase precipitation may have also been spread more evenly throughout the year than now, with proportionally more falling in winter as snow. Both observations have significant implications for afromontane foragers, who, our radiocarbon dataset indicates, were surprisingly active at such times, perhaps because the environment was less unproductive than previously thought, with riverine resources becoming more abundant even as their terrestrial counterparts dwindled. The recurrent intensification of riverine fishing during the early LGM, ACR, and Neoglacial (Stewart and Mitchell, in press) represents one of numerous flexible responses documented

archaeologically for Maloti-Drakensberg foragers faced with some of the more acute environmental shifts reviewed here.

While considerable progress has been made towards reconstructing palaeoclimates and human-environment dynamics in the Maloti-Drakensberg, much remains to be done. The vast bulk of the region's palaeoenvironmental data, for example, derives from archaeological rockshelters whose sequences are punctuated by major occupational and sedimentary hiatuses, with more continuous, non-archaeological archives limited to the past ~16 ka (Norström et al., 2014). More effort must also be directed towards locating and sampling deeper-time archives, such as alluvial and colluvial-palaeosol sequences. Similarly, greater spatiotemporal coverage is needed for the region's archaeology. Particularly pressing is new research in the eastern Free State and Lesotho's Maloti ranges, where entire valleys and adjacent landscapes remain unexplored, as well as further re-excavation of known rockshelter sequences of great antiquity (e.g. Stewart et al., 2012). Heeding lessons learned from Likoaeng, more stratified open-air sites must be located and investigated in order to capture periods, activities, or living arrangements not represented in rockshelters (Mitchell et al., 2011). Methodological advances are necessary for building interpretative bridges between different kinds of archaeological records, such as open-air lithic scatters and rockshelter sequences, and between the latter and rock art panels (Bonneau et al., 2017). New approaches to formerly and freshly generated archaeological data are also required to test models of seasonal mobility (Cable, 1984; Carter, 1970, 1978; Opperman, 1987) within the longer-term, climatically diverse occupational pulses discussed here. Finally, developing tools for detecting the presence, antiquity, and ecological impact of landscape modification practices employed by afromontane foragers, and their feedback on cultural systems, is essential if we wish to illuminate the full spectrum of human-environment dynamics in southern Africa's highest region.

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## Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.quascirev.2018.07.014.

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